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February 1996

Abrasion Resistant, Volatile Organic Compound (VOC) Compliant Coatings for Hydraulic Structures

by *Alfred D. Beitelman*
U.S. Army Construction Engineering Research Laboratories

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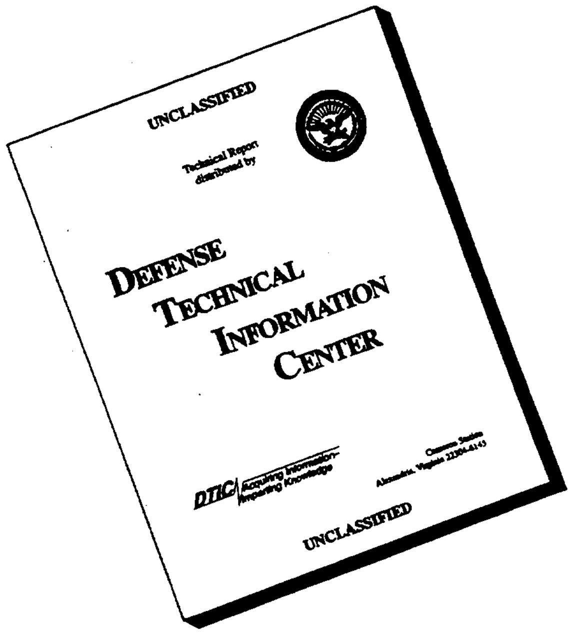

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Abrasion Resistant, Volatile Organic Compound (VOC) Compliant Coatings for Hydraulic Structures

Key

Manufacturer	System Number	System
Ameron P.O. Box 1020 Brea, CA 92621 (714) 529-1951	Basecoat for all systems	MIL-P-24441/29 F150 Type IV Green Epoxy Primer MIL-P-24441/30 F151 Type IV Haze Gray Epoxy Topcoat
Online Systems 30 Endicott Street Danvers, MA 01923 1-800-876-2543	25	Irathane FW-40 Primer Irapair 255NM Topcoat
Online Systems	26	Irathane FW-40 Primer Irapair 155NM Topcoat
United Coatings East 19011 Cataldo Greenacres, WA 99016 1-800-541-4383	27	Primer 302 Uniflex 455 Topcoat
Tnemec Company, Inc. P.O. Box 411749 Kansas City, MO 64141-1749 (816) 483-3400	28	Series 143 Elasto-Shield Beige and Gray
Ameron	29	Amerthane 487
Wasser High-Tech Coatings 8041 South 228th, Bldg. 103 Kent, WA 98032 (206) 850-2967	30	MC-Conseal Primer MC-Elastothane Topcoat
Thane-Coat 10400 Westoffice Drive No. 120 Houston, TX 77042 (713) 780-0990	31	Primer 300 Ultrathane CS-150-S Topcoat
Thane-Coat	32	Primer 400 Ultrathane CS-100 Topcoat
CIM Industries, Inc. 94 Grove Street Petersborough, NH 03458 1-800-543-3458	33	CIM 1000
Futura Coatings, Inc. 9200 Latly Avenue Hazelwood, MO 63042 (314) 521-4100	34	Futura-Thane 585

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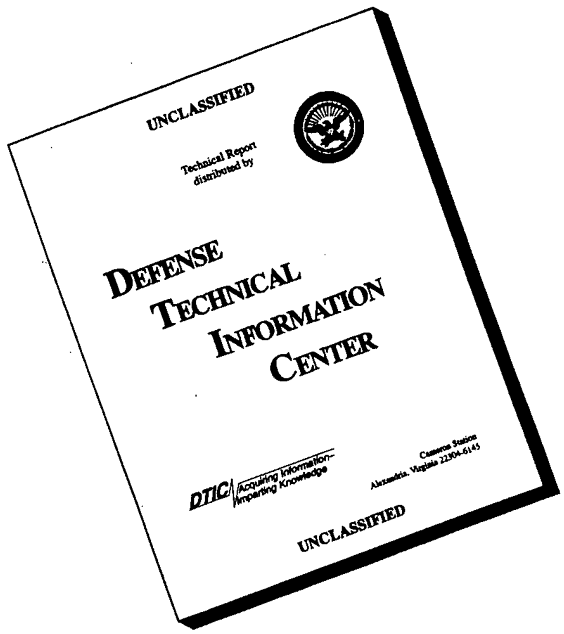

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Repair, Evaluation, Maintenance, and Rehabilitation Research Program

Technical Report REMR-EM-9
February 1996

Abrasion Resistant, Volatile Organic Compound (VOC) Compliant Coatings for Hydraulic Structures

by Alfred D. Beitelman

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Preface

This study was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Electrical and Mechanical problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under the Civil Works Research Unit 32667, "Universal VOC Compliant Coating System for Locks and Dams for which Mr. Alfred D. Beitelman is the principal investigator. Mr. John Gilson (CECW-EE) is the technical monitor for this work.

Mr. David B. Mathis (CERD-C) is the REMR Coordinator of the Directorate of Research and Development, HQUSACE; Mr. Jim Crews and Mr. Tony C. Liu (CECW-EG) serve as the REMR Overview Committee; Mr. William F. McCleese, U.S. Army Engineer Waterways Experiment Station, is the REMR Program Manager; Mr. Alfred D. Beitelman is the Problem Area Leader for the Electrical and Mechanical problem area.

This work was conducted by the U.S. Army Construction Engineering Research Laboratories (USACERL) under the general supervision of Dr. Ellen Segan, Chief of Facilities Engineering Division (FL). The USACERL technical editor was Linda Wheatley, Technical Resources Center.

Portions of the laboratory work were conducted at the Department of Interior Bureau of Reclamation Laboratory under the guidance of John Baker with assistance from K.K. Karpoff and Stephen C. Reo. The laboratory work done at USACERL was under the guidance of Mr. Beitelman with assistance from Troy Avery and Dennis Hoffman. Field applications were conducted in the Rock Island and St. Paul Districts.

COL James T. Scott is the Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is the Technical Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]
gallons (U.S. liquid)	3.785412	liters
centipoises	1×10^{-3}	pascal seconds
inches	25.4	millimeters
mils	0.0254	millimeters
pounds	453.6	grams
pounds/square inch	6.894	kilopascals

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

ABRASION RESISTANT, VOLATILE ORGANIC COMPOUND (VOC) COMPLIANT COATINGS FOR HYDRAULIC STRUCTURES

PART I: INTRODUCTION

Background

1. The Corps of Engineers has used solution vinyl paints for the corrosion protection of hydraulic structures on inland waterways for many years. These coatings have an excellent service life; however, the liquid paint contains high quantities of solvents. Recently enacted air pollution regulations on volatile organic compounds (VOCs) put severe restrictions on solvents contained in paints. Specifically, these regulations limit the amount of organic solvents that may be contained in the liquid paint. Use of low solids paints, such as solution vinyls, violate some of the existing state regulations and future state regulations may, in effect, eliminate the further use of these coatings by the Corps of Engineers. Therefore, to comply both with existing and anticipated regulations, it is necessary to evaluate potential coatings to replace those currently used.

2. A previous study (Baker and Beitelman 1992) evaluated a number of coatings for use in nonabrasive areas on dams. The study included the field application of a number of coatings, mostly epoxies, to hydraulic structures. Continued field monitoring of these test coatings has revealed their extremely poor performance in more abrasive areas such as the downstream waterline areas of navigation dams. As a result, additional work was initiated to determine if the application of an abrasion resistant urethane topcoat to one of the most corrosion resistant epoxy systems would provide a level of protection similar to that provided by the currently used vinyl systems.

Objective

3. The investigation had the following objectives:

a. Document the performance of proprietary, VOC compliant, polyurethane elastomers in a variety of laboratory conditions designed to emulate real-world environments and identify specific coating systems as candidates for field testing.

b. Conduct field evaluations to verify field application and performance of the coatings.

c. Provide test methods and performance data for use in writing performance specifications for polyurethane-topcoated epoxy systems.

Approach

4. A telephone survey and a review of manufacturers' data sheets were used to select the specific commercially available coating systems to be tested in the investigation. The common epoxy basecoat chosen was MIL-P-24441/29 F150, Type IV primer and MIL-P-24441/30 F151, Type IV topcoat. This epoxy system is the latest and lowest-VOC version of MIL-P-24441. The elastomeric polyurethanes were chosen on the basis of their generic types, the equipment requirement for application (plural-component applied systems were excluded), and their commercial availability from established manufacturers. Coatings showing the greatest level of performance in laboratory testing were applied to field structures.

Products Tested

5. Ten coating systems representing the following generic or application variations of elastomeric polyurethane intermediate and topcoats were tested over a common MIL-P-24441, Type IV epoxy system basecoat:

a. A troweled elastomeric aromatic-aliphatic polyurethane over a brushed aromatic isocyanate adhesive primer.

b. A sprayed elastomeric aromatic-aliphatic polyurethane over a sprayed aromatic isocyanate adhesive primer.

c. A brushed elastomeric aromatic-aliphatic polyurethane over a brushed isocyanate polyol primer.

d. A brushed elastomeric aromatic polyurethane.

e. A brushed aromatic moisture-cure polyurethane over a brushed moisture-cure mixed aromatic isocyanate primer.

f. A sprayed elastomeric aromatic polyurethane over a sprayed one package isocyanate bonding primer.

g. A troweled elastomeric aliphatic polyurethane over a sprayed two-package isocyanate aromatic polyurethane adhesive primer.

h. A squeegeed elastomeric aromatic asphalt polyurethane.

i. A sprayed elastomeric aliphatic polyurethane.

Detailed information on the individual coating systems tested appears in Tables 1 and 2.

PART II: LABORATORY EXPERIMENTAL DESIGN

Overview

6. The design for laboratory testing of the coatings was as follows:

a. Test panels of systems that could be applied by brush or trowel were prepared by researchers in the laboratory. The remaining systems were applied by the respective manufacturers.

b. Duplicate panels of each coating system were placed in saltwater (SW) immersion, freshwater (FW) immersion, and QUV-Prohesion accelerated weathering tests.

c. Single, unexposed panels of each coating system were subjected to multiple pulls for the pulloff adhesion test and to abrasive blasting for the abrasion test.

d. Single, unexposed panels of each coating system were subjected to the mandrel bending (flexibility) test.

e. Three unexposed panels of each coating system were set aside for future testing.

Panel Preparation

7. All test coatings were applied to panels cut from sheets of 24 to 38 mil (0.6 to 1.0 mm) cold-rolled steel, Rockwell "B" hardness of 55 to 65, flat polished to 15 to 25 microinches (0.4 to 0.6 micrometers) in roughness, ASTM A 109, A 366 specifications. Immersion panels were 3 by 6 inches (76.2 by 152.4 mm) with a 1/4-inch (6.4 mm) hole centered along one 3-inch (76.2 mm) edge, 1/4 inch (6.4 mm) from the edge. Panels used for QUV-Prohesion accelerated weathering tests were 2-5/8 by 6 inch (66.7 by 152.4 mm) and had no hole. All panels were cured for a minimum of 14 days in a controlled temperature and humidity room (73 ± 3 °F [22.8 ± 1.6 °C] and 50 ± 2 percent relative humidity) before testing.

8. All test panels were abrasive-blasted in the laboratory using a Uni-Blaster, a totally enclosed blasting cabinet manufactured by Inland Manufacturing Company. The blasting media used Humble Abrasive Flint, Grade 3, produced by Humble Sand, Inc. The gun was operated at a

pressure of 90 lb/sq in (620 kPa) and had a 5/32-inch (4.0-mm) air jet with a 5/16-inch (7.9 mm) tip. Estimated abrasive consumption was 0.628 pounds (285.1 grams) per minute of operation. This figure was obtained by dividing the estimated quantity of abrasive used, 150 pounds (68.2 kilograms), by the total minutes of operation during the blasting media impact abrasion test, computed to the nearest minute. Abrasive was fed to the gun by aspiration. All test panels were abrasive-blasted on both sides to a profile of 2 to 3 mils (0.05 to 0.08 mm). Previous spot checking with Testex tape indicated the abrasive blast achieved an average profile of 2.25 mils (0.06 mm). The panels of five of the coating systems were both abrasive-blasted and coated in the laboratory. Application was with polyfoam applicators (a putty knife type blade). Laboratory basecoated panels were sent to the manufacturers for the applicaton of coating systems No. 26, 31, 32, 33, and 34. Completed and returned panels were marked on both sides (both sides were coated with the complete coating systems) with the coating systems numbers, number of a panel within a given coating system number, and the side number of the panel (either 1 or 2).

9. Efforts were made to achieve the "target" or recommended dry-film thicknesses (DFTs) of the coating system. Both wet and DFT measurements were used to monitor the thicknesses of the coatings applied in the laboratory. In no instance were fewer than the recommended minimum number of coats applied, although additional coats were applied as necessary to ensure that the minimum DFTs for a given coating system would be achieved. Final total DFTs were measured with an Electro-Physik minitest 3001 with an F5 head using the average of five readings taken at approximately the same location on all panels. The reading locations formed the corners of a box with a dot at the center. Panels were rejected if the reading in the immersion area of the panel was statistically, significantly below average. The "testing sides" of the four immersion panels for the immersion tests of an individual coating system were chosen on the basis of proximity to both the target total DFT and to one another. If necessary, a "high" and a "low" panel were paired in each test. The same criteria were used to choose the "testing sides" of the test panels for the QUV-Prohesion

accelerated weathering test. The DFTs of the "back sides" as well as the "testing sides" of the panels were recorded. The remaining panels were put aside for use in testing adhesion, flexibility, and future testing. All panels selected for the immersion and QUV-Prohesion accelerated weathering tests were edge-sealed and the immersion panels marked SW or FW. The internal test numbers of the duplicate panels, 1 or 2, were also marked. Initial color readings were taken on all of the panels selected for immersion or QUV-Prohesion testing following the minimum aging period in the constant temperature and humidity room.

Pot Life

10. Pot lives for the two component coating systems applied in the laboratory were checked during the application phases of panel preparation. The coating materials being applied to the test panels were observed from the time of mixing until the time the materials became unusable. The time was adjusted for the temperature of application and checked against the manufacturers' data for pot life. Pot lives were again checked for all elastomeric polyurethane topcoats during the investigation of the viscosity profiles, which are described later in the text.

Recoating Time

11. Recoating times for the systems applied in the laboratory were checked as a part of the application phase of panel preparation. Manufacturers' suggested recoating intervals were closely adhered to and recoating properties and curing times were monitored. All times were extrapolated to the times required at the temperatures of application using the manufacturers' data as a base. The panels were examined visually for any signs of lifting, delamination, etc., at the time of recoating and again before any additional coats were applied.

Curing Time

12. Curing times for coating systems applied in the laboratory were also checked as a part of the application phase of panel preparation. The coatings were examined visually and by touch. When the coatings were examined by touch, suitable solvents were used to clean off contaminants before any further coating application was permitted.

Immersion Testing

13. Both the SW and FW immersion tests were based on ASTM D 870. Both immersion tanks had internal dimensions of 36 by 18 by 9-1/2 inches (914.4 by 457.2 by 241.3 mm). Each tank was aerated with two aquarium-style air pumps and diffusers, and both were operated at a temperature of 100 ± 2 °F (37.8 ° ± 1.1 °C). Both tanks were emptied and cleaned after 1,500 hours of operation and after the last sets of panels had experienced 3,000 hours of exposure.

14. The SW used in the test conformed to ASTM D 1141. Formula A for substitute ocean water was used. To prevent disposal problems, heavy metals were not added. The "sea-salt" in formula A was purchased and mixed with deionized water according to the supplier's instructions. The "sea-salt" solution was adjusted to pH 8.2 using a 0.1N solution of sodium hydroxide. Deionized water with no additives was used in the FW immersion test.

15. Although ASTM D 870 describes the testing of scribed coatings on ferrous substrates as being impractical because of contamination from corrosion products, the panels were scribed with an "X" on the bottom half of the "test" side so the effects of immersion could be observed on the stressed (scribed) "test" sides as well as on the unstressed (continuous film) back sides of the panels. After the tanks were filled to the reference mark, the suspended test panels were immersed

approximately three-quarters of their length. A float-type controller maintained the liquid level in the immersion tanks.

16. The test panels were examined weekly. The test panels exposed to SW were rinsed with deionized water before they were examined. All of the test panels were examined visually for rust along the scribe, blistering, etc. Records of the elapsed hours of immersion were carefully maintained. All elapsed times that were recorded are the elapsed times as of the dates the panels were checked, not the precise times at which the events (blistering, etc.) took place.

17. The basic immersion period was 3,000 hours for both SW and FW. Laboratory experience with this test had indicated that many failures occurred between 1,000 and 3,000 hours. Test panels that had not blistered by the end of the immersion period were set aside for further testing. Experience has shown that panels that survive 3,000 hours in immersion testing usually survive long periods of additional immersion testing. At the end of the 3,000-hour immersion period, the test panels were photographed and measured for color. Any panels that exhibited blistering on the scribed or "test" sides were checked for blistering on the unscribed or back sides, also.

18. Color was measured before and after immersion at the bottom of the scribed portion of the panels. After immersion, the testing areas were wiped with a tissue before the readings were taken to remove all loose soiling materials. Consequently, the color change data contain several components. Among them are possible leaching, staining, and soil retention.

QUV-Prohesion Accelerated Weathering Testing

19. The QUV portion of the tests was conducted in accordance with ASTM D 4587 and ASTM G 53. QUV-Prohesion accelerated weathering testing was conducted to determine the above-the-waterline behavior of the coating systems reported on in the immersion testing section (page 7).

Chalking, gloss, blistering, and color difference were checked to determine the effects of ultraviolet exposure and a corrosive atmosphere on aesthetic behavior and corrosion resistance. A rating of 10 is no chalking, and a rating of 2 is very heavy chalking. Colorimeter readings were taken before and after exposure using Illuminant C for one set of readings and Illuminant D65 for a duplicate set of readings for comparison. Illuminant C simulates an overcast day and Illuminant D65 simulates bright daylight. Illuminant D65 has the lower color temperature and gives readings that are cooler (i.e., bluer) than those of Illuminant C. QUV-Prohesion accelerated weathering testing was conducted using a QUV unit manufactured by Q-Panel Company. UVB-313 ultraviolet lamps were used. A 4-hour condensation and 8-hour ultraviolet exposure cycle was used. The unit was operated continuously during the QUV portion of the test. Operating temperatures were 60 to 65 °C (140-149 °F) for the ultraviolet cycles and 40 to 45 °C (104-113 °F) for the condensation cycles. Lamp rotation and replacement were conducted at intervals of between 400 and 450 hours. The Prohesion portion of the tests was conducted using a Q-FOG cabinet, Model SF/MP1000. The "Mebon Prohesion Test" was carried out as follows: a cycle consisted of a 1 hour salt fog at ambient temperature followed by 1 hour of drying at 35 °C (95 °F); atomization pressure for the salt solution was 22 lb/sq in. (152 kPa); and pump speed was set at 1.1 liters of solution per hour. The salt solution consisted of 0.5 grams/liter NaCl (sodium chloride) plus 4.0 grams/liter NH_4SO_4 (ammonium sulfate). The reservoir held 114 liters of the solution. An overall sequence of 1 week of testing in the QUV cabinet followed by 1 week of testing in the Prohesion cabinet was used. Total time of the combined tests was 3,000 hours, minimum. This type of combined test has been referred to as a "cyclic corrosion weathering method." After 3,000 hours of testing, the test panels were examined for color change, chalking, loss of gloss, and other damage. Duplicate test panels were exposed for each coating system. All test panels were scribed with an

"X" on the bottom half of the "test" side and were visually inspected for chalking or other defects once a week. All recorded elapsed times were the dates the panels were checked, not the precise times at which the events (first evidence of chalking, etc.) took place.

Pulloff (Elcometer) Adhesion Testing

20. ASTM D 4541 was conducted using an Elcometer adhesion tester with a range of 0 to 1,000 lb/sq in (0 to 6,894 kPa). An annular bearing ring was used to keep the resultant force normal to the surface. A circular hole cutter (dolly cutter) was used to score through to the substrate around the loading fixtures. The dollies were adhered to the coating surfaces using the prescribed surface preparation method and Araldite AW106/HV953 epoxy adhesive, which cures in 24 hours. Pressure perpendicular to the surface was applied to the dollies for a minimum of 24 hours during the epoxy's curing time. Shortly after the 24-hour cure had been completed, the adhesion tester was connected to a dolly on a panel under test. All panels were tested at approximately the same elapsed time after the dollies were adhered to the coatings. The tests were carried out at ambient laboratory temperatures. Control panels were given triplicate (three dollies) testing. The degree of adhesive versus cohesive failures, as well as the pulloff values, were noted.

21. After unexpected adhesion failures occurred in field testing, an additional adhesion test was performed on extra immersion-type panels remaining from the laboratory investigation on Systems No. 26, 29, 30, and 31. ASTM D 1151-90, "Standard Test Method for Effect of Moisture and Temperature on Adhesive Bonds," was selected as the guide for testing. Both room temperature (RT)(Condition 1) [73.4 °F (23 °C)] and boiling [212 °F (100 °C)](Condition 2) deionized water immersion tests were run. After the completion of the immersion tests, the panels were checked for pulloff adhesion according to ASTM D4541. Since systems No. 26 and 31 were of the greatest interest, they were specially prepared

for testing by peeling one panel of each along the edges to expose the interfaces of the coatings (Condition 3). Test conditions are as follows:

Condition 1 Soaked at RT for 67 days (1,608 hours), allowed to dry, then given pulloff adhesion tests

Condition 2 Soaked at RT for 1,602 hours; boiled for 6 hours, allowed to dry, then given pulloff adhesion tests

Note: Systems No. 29 and 30 bubbled badly during the boiling test. The irregular surfaces created would not permit the suction cup to seal. In addition, System No. 29 became gummy. The term "bubbling" is used because the irregularities in the film were caused by the expansion of air bubbles within the film; the "bubbles" were "dry," not "wet."

Condition 3 Soaked at RT for 962 hours, boiled for 28 hours, allowed to dry for 73.5 hours, then given the pulloff adhesion test.

Note: The panels were peeled along the edges to expose the interfaces of the coatings.

Mandrel Bend Testing

22. ASTM D 522, the mandrel bend test, was run on a spare coated immersion-type panel for each coating system. A Gardner mandrel set was used to run the tests. Each coating system was bent around a 1-inch (25.4 mm) mandrel. The nature of any failure that occurred was noted.

Color Measurement

23. ASTM D 2244 was used to compute color difference data in CIE 1976 CIELAB (L*, a*, b*) color space. The L*, a*, b* Color System was selected because of its ability to simply and graphically describe the nature and direction of color shifts between two panels. It can also be used to describe the magnitude of the total color shift between the panels. Briefly, the L*, a*, b* color mapping system consists of L* (lightness), +a (red), -a (green), +b (yellow), and -b (blue). Consequently, an increase in L* indicates a lightening of the color, an increase in the +a direction indicates a reddening of the color, an increase in the +b direction indicates a yellowing of the color, etc. Total color difference, or ΔE^*ab, is measured as follows:

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Illuminant C was used to take the color readings for the immersion tests, and both Illuminant C and Illuminant D65 were used to take the color readings for the QUV-Prohesion accelerated weathering tests. Illuminant C is the more widely known and used illuminant; Illuminant D65 gives more realistic readings for actual exposure in daylight. Color measurements were made with a Minolta CR-200b Chroma Meter. Readings on the immersion panels were taken before immersion and after 3,000 hours of immersion on the test sides of the panels within the scribes and below the intersections of the scribes. After exposure, the test areas were wiped with a tissue to remove loose contaminants. Readings on the QUV-Prohesion panels were taken on the test sides of the panels on the upper half above the scribes. They were taken before exposure and after 3,000 hours of exposure.

Chalking Test

24. Chalking was evaluated according to ASTM D 4214. A black cloth was used to test most of the coating systems. However, in a few instances, it was necessary to use a white cloth because the chalky material was dark colored. Pictorial Standards of Coatings Defects (Federation of Societies for Coatings Technology, 1979) was used as the source of the visual chalking reference standards.

Blistering Test

25. ASTM D 714 and the visual standards in Pictorial Standards of Coatings Defects (FSCT 1979) were used to evaluate blistering. Blistering on the extreme edges of panels was discounted. Blisters were rated on both size and frequency. If blistering occurred only in certain limited areas, this fact was noted.

Brookfield Viscosity Studies

26. Brookfield viscosity studies were conducted on the elastomeric polyurethane topcoats to establish the general viscosity levels and profiles of the materials and to compare stated pot lives with experimental ones. The testing was done on a Brookfield Digital Viscometer, RVTDV-II, with eight speeds, a choice of seven spindles, and the guard leg in place. A water bath, Brookfield Model EX200, with a modification in the lid to make the addition of cooling ice easier, was used to maintain the temperature of the samples throughout the tests. The water in the bath was mechanically circulated and maintained at a temperature of 76 to 78 °F (24.5 to 25.5 °C) during the tests. A Brookfield Graph Plotter continuously plotted the percent of full scale of the viscosities at the particular revolutions per minute (rpm) and spindle sizes being used. Test Methods A and B (ASTM D 2196) were

followed, except that no rest period was taken after a down "ramp" had been completed. "Ramps" were periods where the rpm were increased (up "ramps") followed by decreased rpm (down "ramps"). Full ramps consisted of rpm from 0.5 to 100 in each direction. However, limitations of the viscosity-spindle relationships permitted only partial ramps in many instances and none at all in one. Ramps were taken at the approximate halfway points of the stated pot lives of the elastomeric topcoats and very close to the ends of their stated pot lives or at the conclusion of the tests. Only the half-way ramps are reported, since they accomplished their purpose of establishing the viscosity characteristics of the coatings (shear-thinning, etc.). All of the coatings were tested in their as-supplied (unthinned) condition. The basic rpm for testing (with the exception of ramps) was the slowest speed, 0.5 rpm. This speed was chosen to establish the apparent viscosities of the coatings and to measure the changes in viscosity of the coatings over time while they were at the closest speed to an "undisturbed" condition. Efforts were made to take readings at 5 to 10 minute intervals, including 15, 30, 60, etc. minutes, or as close to those benchmark times as circumstances permitted. Before running the viscosity studies, the equipment was checked with 1,000 cps and 5,000 cps Brookfield viscosity standards and found to be within tolerances. At the end of the tests, the coatings were checked empirically for their application characteristics. Figures 1 through 8 are graphs of the viscosity studies and ramps.

Abrasion Testing

27. Abrasion testing was carried out using a laboratory designed test. The abrasive blasting cabinet and blasting media are described in paragraph 8. Only fresh (no recycled) flint blasting media was used for this test. An apparatus was constructed that placed the blast nozzle 4 inches (101.6 mm) in front of the test panel and the test panel at a 45-degree angle to it. Air pressure was set to 90 lb/sq in (620 kPa). A

5/32-inch (4.0-mm) air jet and a 5/16-inch (7.9-mm) tip were used. The test panels were weighed before and after testing and the weight losses recorded. Maximum testing time was 30 minutes. If a test panel failed to complete the full 30 minutes, it was removed from the test and the elapsed time before removal was recorded. Failure to complete the test was defined as the appearance of the epoxy basecoat anywhere in the blasted area. A panel of a widely used epoxy coating system (17.2 mils thick) left over from the Baker and Beitelman (1992) study, was tested for comparison purposes. Figure 9 shows results of the blasting media impact abrasion test on Systems No. 26 through 34.

Gloss Testing

28. The QUV-Prohesion panels were gloss tested before and after exposure. A Micro Tri-gloss meter with 20°, 60°, and 85° geometries, distributed by Byk-Gardner, was used to take the gloss measurements. ASTM D 523 procedures were followed when taking the gloss measurements.

PART III: RESULTS

29. For a detailed consideration of the results, refer to Tables 1 through 10. For a summary of the results, refer to Tables 11a and 11b. Table 12 shows available manufacturer's test results. Table 13 shows the results of the post field test adhesion study.

PART IV: DISCUSSION

Coating System Performance

30. System No. 25 is a trowelling compound intended for repair work. Some test panels prepared in the laboratory developed small, shallow cracks. The manufacturer explained the cause as small localized areas of imbalance between the base and curing agent. Hand mixing was used during the preparation of the panels. Overall, this system performed well. However, as the manufacturer made clear, more thorough than usual mixing is required. As would be expected for a troweling compound, the viscosity was highest of any system tested and too high for a ramp. The workable pot life was appreciably shorter than the stated pot life of 1.5 hours given in the data sheet. Blasting media impact abrasion resistance was very good at 13.8 mg/min loss, the third lowest loss of any of the systems tested. Performance in the SW and FW immersion tests and in the QUV-Prohesion test was uniformly good, with no blistering. As with all the systems tested, there was undercutting of more than 1/8 inch (3.2 mm) at the top "V" of the intersection of the scribes. For brevity, this will be referred to simply as "unsatisfactory undercutting" in the remaining paragraphs of Part IV. The system's chalk rating (QUV-Prohesion) was excellent (rating 10) and color changes (ΔE^*_{ab}) in the immersion tests were 12.56 and 13.46, and in the QUV-Prohesion test, 10.03. The color change figures are among neither the highest nor lowest for all systems. Topcoat recoating times at 75 °F (23.9 °C) are a minimum of 20 minutes and a maximum of 1 hour, the shortest times of any system tested. However, the cure times would be adequate for field application with a trowel. Cure time at 75 °F (23.9 °C) before immersion is a minimum 4 days. A minimum of three coats is required to achieve 60 mils (1.5 mm) DFT of elastomer (including a primer/bond coat). Pulloff adhesion, although the lowest of all systems tested at 205 lb/sq in (1,413 kPa), should be adequate for practical

purposes. Consultants have stated verbally that 220 to 250 lb/sq in (1,517 to 1,724 kPa) are adequate for some applications but may not be sufficient where abrasion is extreme. Overall, System No. 25 performed satisfactorily in laboratory testing.

31. System No. 26 is a sprayed-on elastomeric polyurethane from the manufacturer of System No. 25. Performance in the immersion and QUV-Prohesion tests was good with no blistering. However, some "welts" resembling mosquito bites were observed in the SW immersion test. Further immersion will establish whether these develop into blisters. Unsatisfactory undercutting was observed in the QUV-Prohesion test. The viscosity of the system, although high, was relatively stable. Its viscosity vs. time curve had a flat slope, and its ramp indicated a high degree of shear thinning and near pseudoplastic flow. The system performed satisfactorily on the blasting media impact abrasion test. Its value of 28 mg/min loss was near the middle of the values for all systems. The system's chalk rating in the QUV-Prohesion test was 8. After immersion in SW, the color change (ΔE^*_{ab}) was only 4.38 CIELAB units, the lowest of any system, while the FW immersion test produced a color change of 8.19 CIELAB units, the second lowest recorded. In the QUV-Prohesion test, the ΔE^*_{ab} was 10.63. Pulloff adhesion was excellent, 567 lb/sq in (3,909 kPa). Workable pot life was shorter than the stated pot life of 1.5 hours; however, it should be adequate for application in the field. Two coats, including the primer/bond coat, are required to achieve an elastomer DFT of 60 mils (1.5 mm). Topcoat recoating times at 75 °F (23.9 °C) are a minimum of 20 minutes and a maximum of 4 hours. Minimum curing time at 75 °F (23.9 °C) before immersion is a minimum of 4 days. Overall, the system performed well in laboratory testing.

32. System No. 27 has an elastomeric polyurethane topcoat that was tested as part of a total elastomeric coating system for Baker and Beitelman (1992) (Systems Nos. 2 and 24). Performance in the SW immersion test paralleled that of System No. 26—welts but no definite blisters. Performance in the FW water immersion and QUV-Prohesion tests

was good, with no blisters. As with all the systems tested, undercutting was unsatisfactory in the QUV-Prohesion test, although a good chalk rating of 8 and relatively low color change (ΔE^{*}_{ab} of 5.34) was achieved. Color change for the SW and FW immersion tests was an average 9.14 and 13.29, respectively. Stated pot lives for spray (1.0 hour) and brush or roller (2.0 hours) were congruent with the workable pot lives for those methods of application. The viscosity of the system was relatively low and stable. The seemingly unusual rheological behavior of Systems No. 27 and 34, each of which had a lower final than initial viscosity, is because the coatings had not recovered from a final ramp (values not reported at the conclusion of the tests). The "official ramp" revealed System No. 27 to be mildly thixotropic. Pulloff adhesion was 333 lb/sq in (2,296 kPa). Loss in the blasting media impact abrasion test was 178.6 mg/min, approximately 11.5 percent of the loss of the epoxy control. A minimum three coats, including a primer/bond coat, were required to produce a DFT of 60 mils (1.5 mm). The elastomeric topcoat recoating times at 75 °F (23.9 °C) are a minimum of 2 hours and a maximum of 72 hours. At 75 °F (23.9 °C), a minimum of 4 days is required for curing before immersion. Although its blasting media impact abrasion resistance was low, System No. 27 performed satisfactorily overall in laboratory testing.

33. System No. 28 is a self-priming, elastomeric, aromatic polyurethane. It is the only system that exhibited blistering during SW immersion. Panel No. 1 had blistering on both the front and back, while panel No. 2 had blistering on the front only. When the blisters were cut open, the intact basecoat appeared. Removal of the basecoat revealed no corrosion; the surface was shiny. The coating system of one panel was cut back from the scribe line and revealed that the basecoat was tightly adhered. A sharp line of demarcation existed between the uncorroded coated area and the corroded scribe line; there was no rust creep under the scribe. System No. 28 provided valuable information that would not have been obtained had blisters not appeared. No

blistering occurred in FW immersion. Color differences in the SW and FW immersion tests were 10.44 and 11.77 CIELAB units, respectively. After subjecting the system to the QUV-Prohesion test, the panel exhibited unsatisfactory undercutting. The coating was given a chalk rating of 6 and showed a color difference (ΔE^*_{ab}) of 8.01 CIELAB units. The rheology of System No. 28 was very interesting. It had a prolonged dip in the viscosity vs. time curve, probably due to elimination of the rest period after completion of a ramp. However, it had the best defined thixotropy hysteresis loop. The stated pot life of this system was 2.5 hours, but workable pot life was found to be less than 2.0 hours at the temperature of investigation. The blasting media impact abrasion test resulted in a loss of 75.1 mg/min, approximately 5 percent of the loss experienced by the epoxy control. Pulloff adhesion was 477 lb/sq in. (3,288 kPa), nearly average for all of the systems. Recoating requires a minimum of 6 hours of curing but cannot exceed 48 hours at 75 °F (23.9 °C). To build a 60 mil (1.5 mm) DFT requires at least 6 coats. Before immersion, a minimum of 7 days curing time is required at 75 °F (23.0 °C). The base coating is very heavy in the container, but hand stirring and mixing with the curing agent produced a smooth, good flowing coating. The manufacturer of this system plans to modify and upgrade it.

34. System No. 29 is also a self-priming, elastomeric, aromatic polyurethane system. It showed no blisters in either the SW or FW immersion tests. Neither was there blistering of the coating during the QUV-Prohesion test, but there was unsatisfactory undercutting. In this test, the system had a chalk rating of 8 and a ΔE^*_{ab} of 7.54 CIELAB units. Color differences in SW and FW tests were 24.18 and 25.02 CIELAB units, respectively. Pulloff adhesion was a good 512 lb/sq in. (3,530 kPa). Both the viscosity vs. time curve and the hysteresis loop were relatively flat. In the media impact abrasion test, the loss of coating was calculated at 39.6 mg/min, approximately 2.5 percent of the epoxy control's loss. Workable pot life for spray application was less than the stated pot life of 1.25 hours; however, the paint was still

brushable at that point. Air tended to be entrained in the liquid topcoat as a result of the stirring and mixing process. The entrapped air resulted in the formation of a number of small "balloons" in the QUV-Prohesion test. Apparently, the heat of the QUV ultraviolet cycle expanded the air bubbles permanently. Examination of the bubbles revealed them to be dry inside and completely contained within the elastomeric topcoat. The damage was strictly cosmetic. Special care in agitating and mixing the components of the topcoat would be advisable. At 75 °F (23.9 °C), the coating cannot be recoated before 6 hours of curing or after 168 hours. The coating was easily built to a DFT of 60 mils (1.5 mm) with just three coats. A minimum curing time of 7 days at 75 °F (23.9 °C) is required before immersion. Overall, System No. 28 tested satisfactorily in the laboratory.

35. System No. 30 is the only system tested that has a moisture cure (MC) elastomeric polyurethane topcoat. Since it consists of only one component, it does not have a stated pot life; however, as it reacts with the moisture in the air, the viscosity can spike upwards very quickly. The viscosity vs. time curve had a flat slope until the 2-hour mark, when it became fairly steep. A crust that formed on top may have accounted for this, since the coating was still brushable and borderline sprayable below the crust after 2.25 hours. Mild thixotropy was observed on the Brookfield viscosity ramp. No blisters formed in the coating during the SW and FW immersion tests; however, blistering appeared after 2,340 hours during the QUV-Prohesion test. Corrosion was present under the blisters as well as under the "v" of the scribed x. Although the color difference was high, 19.02 CIELAB units, the coating showed little chalking and was given an 8 rating. The color differences in the SW and FW immersion tests were also high at 17.28 and 39.55 CIELAB units, respectively. Performance in the media blasting impact abrasion test was good; the topcoat disappeared at just 18.6 mg/min. The pulloff adhesion was 320 lb/sq in. (2,206 kPa). Recoating times at 75 °F (23.9 °C) are 1 hour, minimum, and 72 hours, maximum. A minimum

of four coats is required to achieve a 60 mil (1.5 mm) DFT, including a primer/bond coat. Once the system is applied, however, it requires only 8 hours of curing before it can be immersed, the shortest time of any system tested. With the exception of the QUV-Prohesion test, System No. 30 tested satisfactorily in the laboratory.

36. System No. 31 is a spray applied elastomeric, aromatic polyurethane. It had the lowest overall Brookfield viscosity of any of the systems tested, even though its Brookfield viscosity versus time curve was relatively steep. Consequently, the ramp was almost a straight line, with what little hysteresis appeared giving a false impression of dilatancy. The coating was still thin and sprayable at the 1-hour mark, 15 minutes beyond its stated pot life; however, it could not be applied after 1.5 hours. There were "welts" but no blisters in the SW immersion test, and no blisters in the FW immersion test. ΔE^*_{ab} for the SW and FW immersion tests were 6.82 and 30.38 CIELAB units, respectively. In the QUV-Prohesion test, blistering appeared after 2,508 hours. The unsatisfactory undercutting displayed by all of the other systems was also present. An excellent chalk rating of 10 and a color difference of 15.38 CIELAB units were also recorded after exposure in the QUV-Prohesion test. Pulloff adhesion was a low 240 lb/sq in.(1,655 kPa). System No. 31 was very resiliant to the blasting media losing just 13.4 mg/min of topcoat, the second lowest recorded. Including a primer/bond coat, the minimum coats required to achieve a DFT of 60 mils (1.5 mm) is five. At 75 °F (23.9 °C), the window of time for recoat is just 5.5 hours; the topcoat must cure for at least 30 minutes before coating, however. Seven days of curing at 75 °F (23.9 °C) are required before immersion. With the exception of the QUV-Prohesion test, System No. 31 tested satisfactorily in the laboratory.

37. System No. 32 is a troweling and repair system from the manufacturer of System No. 31. It trowels to a smooth semigloss finish, whereas System No. 25 had a flat finish. System No. 32 had welts, but no blistering in the SW and FW immersion tests and color differences

were a relatively low 7.37 and 13.78 CIELAB units, respectively. After the QUV-Prohesion test, the coating was given a chalk rating of 10; however, the color changed by 22.23 CIELAB units. As with the other systems, undercutting was unsatisfactory. Pulloff adhesion was the highest recorded, 570 lb/sq in (3,930 kPa). Because the Brookfield viscosity vs. time curve was steep, the coating displayed another case of pseudo-dilatancy. The system was heavy, and still leveling after 1 hour. The workable pot life was in line with the stated pot life of 0.75 hour. System No. 32 was the most abrasion resistant, losing just 7.4 mg/min of its topcoat. The urethane can be recoated after 16 hours but must be recoated before 96 hours of curing, when ambient temperature is 75 °F (23.9 °C). In addition, the system requires 7 days of curing at 75 °F (23.9 °C) before being immersed. Two coats, including the primer/bond coat, are required to build a system with DFT of 60 mils (1.5 mm). Overall, System No. 32 performed reasonably well in laboratory testing.

38. System No. 33 is a self-priming, squeegee- or spray-applied, asphalt-modified, elastomeric, aromatic polyurethane; the only one of its type in the testing series. No blisters or "welts" appeared in either the SW or FW immersion tests. Color difference after the SW immersion test was 5.29 CIELAB units, the second lowest, and after the FW immersion test was 6.90 CIELAB units, the lowest of all systems tested. No blistering occurred, but unsatisfactory undercutting was exhibited after exposure in the QUV-Prohesion test. However, this system had the least corrosion in the "V"-shaped undercut area of any system in the test. The color difference in the QUV-Prohesion test, 2.63 CIELAB units, was the lowest of any system tested, and its chalk rating was 10, surprising for a bitumen-containing coating. The abrasion resistance of the coating was near the median for all samples, a loss of 21.9 mg/min. Pulloff adhesion, at 510 lb/sq in (3,516 kPa), was the fourth best of all the systems tested. System No. 33 had the third highest overall viscosity of the systems tested and a steep viscosity

vs. time slope. Some shear thinning occurred on the upside, and viscosity increased relatively rapidly on the downside of the ramp. At its stated pot life of 0.5 hour, the material was thick and unusable. Recoating time at 75 °F (23.9 °C) was between 30 minutes and 4 hours after application. The system was easily built to the 60 mil (1.5 mm) DFT in just one coat using a squeegee; however, three coats are required when spray applying. The coating can be immersed after 24 hours of curing at 75 °F (23.9 °C). Overall, System No. 33 performed well in laboratory testing.

39. System No. 34 is a self-priming aliphatic polyurethane. No blisters or "welts" appeared in either the SW or FW immersion tests. Color difference in the SW immersion test was 33.53 CIELAB units and in the FW immersion test was 33.86 CIELAB units. Blistering occurred after approximately 2,550 hours of exposure in the QUV-Prohesion test, and the unsatisfactory undercutting was also present. The color after QUV-Prohesion changed by 3.54 CIELAB units, the second lowest of the systems tested, and was given a chalk rating of 8. Pulloff adhesion was 500 lb/sq in (3,447 kPa), and the topcoat disappeared at a rate of 62.5 mg/min. The overall viscosity of System No. 34 was the second lowest of all of the systems tested and actually declined from its starting levels because of the ramps. The viscosity vs. time curve was nearly a flat slope. Its ramp indicates "normal" shear-thinning and mild thixotropy. The coating was still sprayable and brushable after its stated pot life of 2 hours. System No. 34 requires one coat to achieve an elastomeric topcoat DFT of 60 mils (1.5 mm). Recoating time at 75 °F (23.9 °C) was between 2 hours and 48 hours. Minimum curing time at 75 °F (23.9 °C) before immersion is 5 days. Overall, System No. 34 performed satisfactorily in laboratory testing.

40. The post-immersion test was performed on systems 26, 29, 30, and 31. Systems No. 29 and 30 had problems with "bubbling" in the boiling water test and could only be tested at RT (Condition No.1). Nevertheless, the mode of failure for System No. 30 (100 percent at the

interface of the bond coat and basecoat topcoat) duplicated the mode of failure observed in the field. System No. 29 exhibited 80 percent failure at the elastomer/basecoat topcoat interface and 20 percent intracoat failure within the basecoat topcoat. Although not as definitive as System No. 30 results, the tendency of the elastomer to disbond from the epoxy was apparent. No difference was discernable between Systems No. 26 and 31, using Conditions No. 1 and 2. Condition No. 3 did produce a distinguishable difference on the middle pull. Only the middle pull "remarks" were reported for all systems instead of the customary average of three pulls. This was done because the middle pulls were reasonably close to the averages and seemed to be as significant. The middle pull on Condition No. 3 gave a clear advantage to System No. 26. Numerical values of the pulloff adhesion in lb/sq in (kPa) form a mixed pattern. The control values reported from a previous test program do show System No. 26 as having the best adhesion. However, considering the accuracy of the method, System No. 29 can be regarded as being in the same adhesion category as System No. 26. Furthermore, System No. 29 exhibited a higher adhesion value than did System No. 26 under Condition No. 1 (the only condition under which System No. 29 could be tested). System No. 26 exhibited decreasing adhesion values under all conditions. It is worth noting that the predominant qualitative mode of failure for System No. 26 was between the polyurethane elastomer and the bond coat. With the direct application of System No. 29 elastomer to the epoxy, failure occurred between the elastomer and the epoxy. System No. 30 was tested only under Condition No. 1, as was System No. 29. The adhesive strength of System No. 30 went down slightly after RT immersion, but its mode of failure was 100 percent at the interface of the bond coat and the epoxy basecoat. System No. 31 increased slightly in adhesive strength after all the immersion tests. However, an increase in adhesive strength in the laboratory did not translate into resistance to delamination in the field.

Estimated Costs

41. Table 2 contains figures on the estimated cost per square foot in dollars for the coating systems investigated. These figures were supplied by the manufacturers of the coating systems and include materials and application, but exclude surface preparation. Because each coating system has its own application and handling characteristics, an individual estimate is needed for each system and the relative complexity of each feature to be coated. The figures presented are based on "average" conditions and quantities and are presented only for the most unspecific comparisons.

PART V: RECOMMENDATIONS FOR FIELD TESTING

42. Based on laboratory testing, the following coating systems are recommended for field testing under either SW (with reservations noted) or FW immersion conditions.

a. The basecoat for the system used in laboratory testing consisted of one coat of MIL-P-24441/29 F150, type IV Green Primer (Epoxy); two coats of MIL-P-24441/30 F151, type IV Haze Gray (Epoxy) topcoat; target DFTs — 3 mils primer, 6 mils topcoat, for a total 9 mils. The use of an epoxy zinc primer should enhance the corrosion resistance at breaks in the film without otherwise affecting the performance of the urethane topcoat. If a 3-mil epoxy zinc primer is used, one of the topcoats can be omitted, thus resulting in a 9-mil basecoat for the system.

b. System No. 26 — Aromatic iscocyanate adhesive primer/bond coat; elastomeric aromatic aliphatic polyurethane topcoat. This system performed reasonably well in all of the tests, although "welts" appeared in the SW immersion test.

c. System No. 29 — Self-priming elastomeric aromatic polyurethane topcoat. This system performed reasonably well in the tests and requires no primer/bond coat. A tendency to entrain air in the mixing process was noticed.

d. System No. 30 — Moisture cure mixed aromatic isocyanate primer/bond coat; elastomeric aromatic moisture cure polyurethane topcoat. This system is the only elastomeric moisture cure polyurethane topcoat tested in the series. It performed reasonably well in the tests, although blistering occurred at approximately 77 percent of the QUV-Prohesion test. This system has the shortest time before immersion, one-third of a day at 75 °F (23.9 °C), of any system tested.

e. System No. 31 — Isocyanate bonding primer/bond coat; elastomeric aromatic polyurethane topcoat. This system performed reasonably well in the tests, although it exhibited "welts" in the SW immersion test and blistering approximately 83 percent of the way through the QUV-Prohesion test. However, it had the lowest mg/min loss (13.4) of any of the systems being recommended for field testing in the blasting media impact abrasion test.

f. System No. 33 — Self-priming (no primer/bond coat) elastomeric aromatic asphalt polyurethane. This system is the only bitumen-modified elastomeric polyurethane topcoat tested in the series. Overall, it had the most consistent and reasonably good performance across the spectrum of tests of any of the topcoats tested. It had the best performance in the QUV-Prohesion test of the topcoats tested; however, because it is a bitumen-containing coating, it could be adversely affected by exposure to direct sunlight. A reflective topcoat would be a possibility for this system.

PART VI: FIELD EVALUATION OF COATINGS

Background

43. Three field applications were performed on tainter gates located on the Mississippi River. Test number one was initiated during August 1992 at Lock & Dam No. 5, Minneiska, MN. Surface preparation and coating application were performed by laboratory and district personnel. Test number two was initiated during October 1993 at Lock & Dam No. 16, Muscatine, IA, and test number three was initiated during June 1994 at the same site. Procurement of coatings and all surface preparation and application at Lock & Dam No. 16 were conducted through modification of an existing contract for painting the gates.

Field Test Number One

Surface Preparation

44. The test area consisted of a section of the gate's downstream waterline area approximately 8 ft tall and across the entire face of the gate. The steel surface was abrasive blasted using river sand. Except around the edges of several rivets, the quality of the blast met the requirements of SSPC-SP 5. The quality of the blowdown was low because only atomization air from the spray gun was used to remove excess abrasive.

Application of E-303d

45. A single kit of E-303d was mixed and sprayed using a conventional agitator pot. The material was thinned approximately 20 percent with ALC-50 and applied to the first 12 ribs and bays counted from the Wisconsin end of the tainter gate. The ambient temperature was recorded as 70 °F with a relative humidity of 50 percent. Dry film thicknesses averaged 3.5 mils.

Application of MIL-P-24441

46. After allowing the E-303d to cure for 16 hours, MIL-P-24441 Formula 150 Type IV epoxy was applied using airless spray. A wet film of 5 to 7 mils was applied without sagging and left to cure. After 4 hours, a coat of MIL-P-24441 Formula 151 Type IV was applied uniformly over the Formula 150. Both Formula 150 and Formula 151 were supplied by the same manufacturer to ensure compatibility and uniformity. Wet film thicknesses of the Formula 151 measured during application were found to be 5 to 7 mils. Once cured, the measured DFT of the entire system ranged from 10 to 20 mils with most measurements between 13 and 14 mils. The ambient temperature ranged from 60 °F to 72 °F with a relative humidity at 11:00 a.m. of 50 percent. The relative humidity reached 100 percent approximately 8 hours after application of the complete system, which delayed application of the urethane topcoats for 40 hours.

Application of System No. 29

47. System No. 29 is a two-component elastomeric polyurethane with a combined volume solids of 68 percent. It requires mixing in a four-to-one ratio using an air driven stirrer. The paint was applied to the first three ribs and bays counted from the Wisconsin side of the gate using airless spray and was applied over the E-303d/MIL-P-24441 system. After allowing the coating to cure for 24 hours, total DFTs were measured and found to range from 35 to 50 mils with an average of 44 mils. The coating was soft and weak and could be easily scraped from the epoxy substrate using thumbnail pressure. The manufacturer's technical support indicated that the coating would become more durable as the curing process progressed.

Application of System No. 31

48. System No. 31 consists of both a bond coat and a urethane topcoat. The bond coat is a two component coating mixed 1:1 and containing 8 percent total solids; the topcoat is a two-component elastomeric sprayable urethane. The test section consisted of the fourth through sixth ribs and bays, counted from the Wisconsin side of

the gate, and the coating was applied over the E-303d/MIL-P-24441 system. Using a brush and roller, the clear admixed bond coat was applied and then left to cure for 10 minutes before being topcoated by the urethane. The urethane requires mixing in the ratio of 3:1 but does not require thinning to be applied with airless spray. To build a system with a 30-mil DFT, the painter had to apply four coats of the urethane. After allowing a 24-hour cure time, the material was found to have cured sufficiently to be very tough with total DFTs ranging from 40 to 60 mils and most measurements within the 40 to 45 mil range.

Application of System No. 26

49. System No. 26 consists of both a bond coat and a urethane topcoat. The bond coat prescribed for use with this system consists of three components mixed together and applied by brush and roller. The bond coat was applied over the E-303d/MIL-P-24441 system on the seventh through ninth ribs and bays of the gate, counted from the Wisconsin side of the dam. After allowing it to cure for 90 minutes, the urethane topcoat was applied using airless spray. The urethane was first applied as a light tack coat and then left to semi-cure before proceeding with heavier buildup. After 15 minutes, two additional passes were applied successively to produce the targeted 30 mil DFT, which was free of sagging. Total DFT measurements 24 hours later ranged from 40 to 65 mils with most measurements in the 45 to 50 mil range.

Application of System No. 30

50. System No. 30 consists of both a bond coat and a urethane topcoat that are single-component, moisture-cure urethanes. The bond coat was thinned 20 percent and applied over the E-303d/MIL-P-24441 system with airless spray to the 10th through 12th ribs and bays of the gate, counted from the Wisconsin side of the dam. After allowing the bond coat to cure for 20 minutes, the urethane was mixed thoroughly for application; however, as the material was mixed, it began to cure. The viscosity rose quickly enough that application by airless spray was not efficacious; therefore, the material was transferred to a pressure pot

and conventional equipment was used. Two coats were applied without sagging and left to cure overnight. After curing for 24 hours, the material was found to be very tough and had total DFTs ranging from 45 to 55 mils with most measurements between 52 and 53 mils.

Evaluation of Coatings in Field Test No. One

51. After application, the coatings were left to cure for 1 week before the lockmaster returned the gate to service. Lock & Dam No. 5 was revisited in 10 months to ascertain integrity of the coatings.

52. System No. 29 exhibited topcoat loss on the leading surface of the ribs in the waterline area, edges were gone, and adhesion was fair. A portion of the topcoat was removed and found to be soft and weak.

53. System No. 31 exhibited topcoat loss on the leading surface of the ribs in the waterline area, edges were gone, and adhesion was poor. A portion of the topcoat was removed and found to be extremely tough; the toughest material applied at this site. The manufacturer's technical support personnel blame the adhesion failure on the sensitivity to moisture during cure of the poly-urea bond coat. It was stated that a less moisture-sensitive bond coat could be supplied if the test were repeated.

54. System No. 26 exhibited topcoat loss on the leading surface of only one rib in the waterline area. Overspray from the application of System No. 30 may have caused the isolated adhesion failure. Elsewhere in the test area the adhesion was excellent; the coating could not be removed from the gate during the knife test. A portion of the coating was removed and found to be extremely tough.

55. System No. 30 exhibited topcoat loss on the leading surface of the ribs in the waterline area, edges were gone, and adhesion was poor with failure occuring between the bond coat and the epoxy. A portion of the topcoat was removed and found to be soft and weak. The removed coating was stretched, and the bond coat cracked while the topcoat stretched.

Field Test Number Two

Surface Preparation

56. The steel surface was abrasive blasted to an SSPC-SP-5 grade using silica sand; the average profile was 3.3 mils.

Application of E-303d

57. E-303d was mixed, thinned between 5 and 10 percent with methyl ethyl ketone, and sprayed with a 45:1 airless unit. It was applied to both the upstream and downstream sides of the gate. During painting operations, the ambient temperature ranged from 47 to 65 °F with a relative humidity between 27 and 86 percent. The coating was applied over 7 workdays with the actual application lasting approximately 15 hours. DFTs ranged from 1 to 6 mils with most measurements averaging 5 mils.

Application of MIL-P-24441

58. The E-303d was cured from 24 to 65 hours before being top-coated with MIL-P-24441 Formula 150 Type IV epoxy. When applied with the 45:1 airless unit, the Formula 150 required no thinning. The entire gate was painted with Formula 150 in 4 hours and not recoated for 48 hours. Application of the Formula 150 epoxy resulted in a measured total DFT of 6 to 10 mils. The Formula 150 was topcoated with MIL-P-24441 Formula 151 Type IV epoxy. Both Formula 150 and Formula 151 were supplied by the same manufacturer to ensure compatibility and uniformity. The Formula 151 epoxy was left to cure for 24 hours. Measured total DFT for the system ranged between 10 to 14 mils. During application and curing, the ambient temperature ranged from 50 to 53 °F with a relative humidity near 41 percent.

Application of System No. 35

59. The gate test area was divided in half with System No. 35 applied to the eastern end of both the upstream and downstream sides. The contractor contacted the manufacturer for field guidance on the application of the system, but the manufacturer did not respond. System

No. 35 is the same as System No. 31 except with a different bond coat. The bond coat is a 100 percent solids, two-component, epoxy primer; the topcoat is a two-component, sprayable urethane. After mixing, the bond coat was thinned with xylene and applied using a 45:1 airless pump. After a 40-hour cure, the urethane topcoat was applied using the same application equipment. The system did not cure. The manufacturer's recommendations were reviewed along with the contractor's mixing operation notes, and it was determined that the urethane topcoat had been mixed 1:1 instead of 3:1, resin to curative, respectively.

Application of System No. 36

60. System No. 36 is the same as System No. 26 but with a different bond coat. At the contractor's request, the manufacturer supplied two on-site representatives to oversee the application. The bond coat is a two-component, 100 percent solids, epoxy primer that can be spray or brush applied; the topcoat is a two-component polyurethane. The gate test area was divided in half with System No. 36 applied to the western end of both the upstream and downstream sides. The bond coat was mixed thoroughly, thinned with xylene, sprayed using a 45:1 airless unit. The application was difficult. The manufacturer's technical data indicated the material could be applied at as low as 40 °F. Temperatures at the time of application were in the low to middle 50s °F; however, the material was so viscous it could not be pumped or atomized satisfactorily. The manufacturer's representatives agreed that thinning was required and that methyl ethylketone (MEK), available at the job site, would be acceptable for thinning. This allowed the material to be pumped, but atomization was still less than adequate. Product information recommended the bond coat cure from 1 to 16 hours before topcoating. The material appeared to have cured properly by the following morning, when the urethane was mixed and applied using the same application equipment. The ambient temperature during application ranged from 44 to 50 °F with an average relative humidity of 66 percent.

Evaluation of Coatings in Field Test No. Two

61. Due to the mixing error of System No. 35, little useful knowledge about the system was gained when the test site was visited 12 months later. The system was easily stripped from the gate using thumbnail pressure and was still somewhat gummy. The urethane topcoat was completely missing from the waterline area and from the edges on the ribs. After 18 months, the topcoat was completely gone from the underwater area of the upstream side of the gate; however, the epoxy system was in near perfect condition with small areas of bare steel visible on approximately 40 percent of the rivet heads. The upstream area above the waterline was still gummy. On the downstream side of the gate some topcoat still remained in protected areas of the ribs but was completely gone from areas that were easily abraded. The epoxy was in excellent condition with bare steel visible only on the sharp edges of the ribs.

62. System No. 36 appeared to have delamination problems when observed at the end of 12 months. The failures were observed both between the topcoat and the bond coat and between individual layers of the topcoat. The adhesion was poor between topcoats wherever a second topcoat had been applied. Adhesion to the bond coat was fair to good. Adhesion of the bond coat to the epoxy was excellent, and the epoxy system was performing superbly. After 18 months, little additional change was noted. The urethane was gone from the bond coat on the face of the lower downstream girder. (This is the most abrasive area of the gate.) Some leading edges of the ribs in the downstream waterline area were also void of urethane. Erosion of the epoxy in these areas exposed as much as 1/4 inch of steel on sharp edges of the ribs.

Field Test Number Three

Surface Preparation

63. The steel surface was abrasive blasted to an SSPC-SP-5 grade using slag abrasive. The blowdown was adequate to remove the dust.

Application of E-303d

64. The E-303d was power mixed for 19 minutes before being added to an agitator pot and applied with a 45:1 airless unit. The entire gate was coated with E-303d and, once cured, measured DFT averaged 3.7 mils. During the painting operation, the steel ranged in temperature from 90 to 112 °F, the initial ambient temperature was 85 °F, and the dewpoint was calculated as 66 °F. The E-303d applied evenly and without incident.

Application of MIL-P-24441

65. After the E-303d had cured for 72 hours, the MIL-P-24441 Formula 150 Type IV epoxy was readied. The contractor mixed the material for 20 minutes and allowed 1 hour of induction time prior to application. Using a 45:1 airless pump with the inlet pressure set at 80 psi, the Formula 150 was applied easily. The entire gate was painted with Formula 150 in 4 hours and left to cure for 48 hours. DFT of the system after application of the Formula 150 epoxy ranged from 6 to 10 mils. The Formula 150 was then uniformly topcoated with MIL-P-24441 Formula 151 Type IV epoxy using the same application procedures. Both Formula 150 and Formula 151 were supplied by the same manufacturer to ensure compatibility and uniformity. The Formula 151 epoxy was left to cure for 24 hours and DFT for the system ranged from 10 to 14 mils. During curing the nighttime ambient temperature dropped to 50 °F with a relative humidity near 41 percent.

Application of System No. 35

66. System No. 35 consists of both a bond coat and a topcoat. Recommendations from the manufacturer suggest applying the bond coat to a 2-mil DFT and allowing the product to cure set-to-touch before

topcoating. Two 45:1 airless units were used to apply the bond coat. Control of coating thickness, especially in complex areas, was difficult. After sufficient curing time, the DFT was measured. It was calculated the bond coat thickness ranged from 2 to 12 mils. Where there was excessive film thickness, the green colored material appeared streaked. The topcoat then was mixed without thinning and applied using a 45:1 airless setup. An initial tack coat was applied to the gate before major film building. The painters tried to apply the paint at 10 wet mils but the film ran and sagged. It was determined that only 5 wet mils could be applied during a single pass. The steel temperature ranged from 84 to 100 °F. Initial ambient temperature was 78 °F and the dewpoint was determined to be 68 °F. The contractor requested on-site technical guidance from the manufacturer; however, the manufacturer offered no personnel.

67. A number of problems were encountered during application. The painters complained that the bond coat was seeping through their clothing and burning their skin. The pot life of the urethane is extremely short (less than 20 minutes at 100 °F). The urethane requires mixing in a 3:1 ratio, which makes it difficult to mix batches smaller than a full 20-gallon kit. The mixing requirements coupled with the short pot life make it exceedingly difficult to apply the system without the material setting up in the pot or lines. After curing, the system was too thin in places and therefore required an additional coat. To topcoat the urethane, once cured, the surface must be roughed up and a bond coat different from the original material must be applied.

Application of System No. 36

68. System No. 36 consists of both a bond coat and a topcoat. The bond coat is a two-component, 100 percent solids, epoxy primer that can be spray or brush applied; the topcoat is a two-component polyurethane. The bond coat has a pot life of just 20 minutes; therefore, it is critical to ensure that all access and equipment is ready before mixing. After 15 minutes of mixing without thinning, the bond coat was ready for

application. A 45:1 airless setup was used and the material was applied to a thickness which yielded a DFT of 4 mils once cured. During application of the bond coat, the temperature of the steel ranged from 62 to 108 °F with an initial ambient temperature of 68 °F and a dewpoint of 62 °F. Once applied, the bond coat appeared nonuniform with light and dark areas that corresponded to light and heavy film thicknesses, respectively. The polyurethane was then mixed without thinning and applied using the same equipment setup.

69. An initial tack coat of the urethane was applied and left to semi-cure before heavy building. Although the manufacturer's product information indicated that the urethane could be built up to "1/8 in. dry thickness...in 2 - 3 coats," the material exhibited severe sagging when built up using only 10 mils of wet film. To get the material to adhere to the bond coat without sagging, the applicators reduced the individual coat wet film thicknesses to between 5 and 8 mils and allowed for a cure time of between 10 and 15 minutes between coats. On horizontal surfaces, the urethane's appearance was satisfactory, but around angles, on the back sides of channels, and on the vertical gate itself, excessive running and sagging occurred. The onsite manufacturer's representatives were unable to give explanations for the product's poor performance during application.

Evaluation of Coatings in Field Test No. Three

70. Lock and Dam No. 16 was revisited 3 months after test initiation. Large sheets of System No. 35 were intact but churning in the waters below the dam. The coating had been torn from areas of high abrasion on the downstream side of the gate. Examined under a microscope, the coating contained arrays of air bubbles. The bubbles confer excellent flexibility upon the coating but offer little resistance to tearing. The bubbles act almost like a perforated page when faced with a tearing type action. Close examination of the gate revealed the bond coat still was adhered to the E-303d/MIL-P-24441 system, but the urethane topcoat had delaminated from the bond coat in some of the most

abrasive areas. In addition to adhesion failures between the bond coat and topcoat, considerable intercoat adhesion failures occurred as well. A knife test performed on areas where the topcoat was still adhering revealed that the coating could be stripped from the dam with medium force. The site was revisited 12 months after application and found to have changed little from the 3-month visit. Loss of adhesion of the urethane to the bond coat had progressed in the areas of abrasion including some areas along the lower edge of the upstream side of the gate. The system remained intact in the recessed areas between the ribs as well as on the majority of the upstream side of the gate.

71. System No. 36, although not degraded to the level of System No. 35, exhibited many similar failures. The coating was missing from the edges of ribs and in the waterline area. In addition, the coating was easily pulled from the bond coat during the knife test. Signs of intercoat adhesion failure were obvious. System No. 36 was no more effective than System No. 35. After 12 months, little change was noted. Loss of adhesion of the urethane to the bond coat had progressed in the areas of abrasion on the downstream side of the gate. The system remained intact in the recessed areas between the ribs as well as on the upstream side of the gate.

PART VII: CONCLUSIONS

72. The most severe laboratory test was the QUV-Prohesion test. Three of the tested systems blistered (with corrosion under the common epoxy basecoats) and all the systems had greater than 1/8-inch (3.2 mm) corrosion undercutting at the scribe lines. Damage to the coating systems, both at the surface and at the substrate, was appreciably greater than the damage done to the REMR-EM-7 (Baker and Beitelman 1992) coating systems, which experienced exposure only to the QUV-accelerated weathering test. The appreciable corrosion damage at the substrates was the result of the corrosive atmosphere present during the Prohesion cycles.

73. All the systems tested passed the 3,000+ hour FW immersion test. Only one system blistered in the 3,000+ hour SW immersion test, although no corrosion was observed at the substrate under the blisters and there was no corrosion undercutting of the scribe lines. An additional four systems had "welts" but no definite blisters.

74. In the post-immersion adhesion tests, exposing the interfaces of the coatings in a system, whereby the wraparound coating layers on the sides of the test panels were peeled off, made the test more severe. More investigation will be needed to determine if exposing the interfaces alone will enable the use of a modified Condition No. 1 (RT only) instead of Condition No. 3. The use of RT instead of boiling deionized water would eliminate the "bubbling" problems experienced with Systems No. 29 and 30. The dominant adhesive failure was at the interface of the epoxy basecoat and the bond coat or, in the absence of a bond coat, the elastomeric polyurethane. With the exception of System No. 30, which had 100 percent Condition No. 1 disbonding of the bond coat/basecoat interface, the proportions of the planes of failure were mixed. Only Condition No. 3, with the interfaces on the panels exposed, replicated the same Systems No. 26 and 31 separation observed in the field. The movement of water laterally under the film would, therefore, appear

to be important, as well as movement vertically through the film. Systems No. 26 and 31 were the ones that performed best overall in the series of immersion tests conducted in this test program. The difficulty of obtaining separation between the two would indicate that System No. 31 was close to continuing the capability of resisting delamination in the field. Conditions No. 1 and 2 produced somewhat contradictory results when the two systems were compared. Condition No. 3, with the interfaces exposed, produced the only indication of separation. System No. 26 had demonstrably better intercoat adhesion and adhesive values than did System No. 31. Although somewhat successful in correlating laboratory and field performance, the tests are still not definitive at this point. More development work will be required to optimize the testing method and to establish the expected degree of correlation with field exposure.

75. Film thickness was not a significant factor in determining coating performance in the laboratory tests. In the blasting media impact abrasion test, it was factored out of the comparison data. Film thickness is more significant in the field. If two coating systems have the same yearly rate of chalking erosion, etc., the thicker coating will have a greater remaining thickness at any given time. For elastomeric polyurethanes, penetration of the film by a "stabbing" or "cutting" action to a given depth will be a smaller percentage of the total depth for a thicker film compared with a thinner film.

76. The data from the investigation, plus Table 12, can be used to write performance specifications. Performance specifications for the exposures envisioned for the coating systems tested include pertinent data obtained experimentally or from the coating manufacturers. The more pertinent values obtained experimentally are those from the immersion, pulloff adhesion, and blasting media impact abrasion tests. The more pertinent values and information obtained from the coating manufacturers are those for generic type, elongation of topcoat, recoating time at a standard temperature, and the minimum curing time

required before immersion after the final coat has been applied, also at a standard temperature. The most commonly referenced standard temperatures are at, or in the vicinity of, 75 °F (23.9 °C). Data on volume solids, maximum VOC, etc., are also included. Examples of minimum and/or maximum topcoat values for the items mentioned are as follows:

Test	Test Value	Remarks
SW Immersion: ASTM D 714-87	Passes 3,000 hours, minimum, at stated testing conditions	For coating systems to be exposed to SW. (Systems No. 26, 27, 31, and 32 are questionable and should not be specified without further and successful SW immersion testing.)
FW Immersion: ASTM D 714-87	Passes 3,000 hours, minimum, at stated testing conditions	All coating systems tested passed the FW immersion test. Three thousand hours have been used for the SW and FW immersion tests because experience has shown that a coating system that passes 3,000 hours will almost invariably continue to pass for many thousands of additional hours.
(Elcometer) Pulloff Adhesion test: ASTM D 4541-89	400 lb/sq in (2,758 kPa), minimum, coating system applied to a minimum 1/8-inch thick steel plate.	Based on the consensus of opinion among coatings technologists consulted.
Blasting Media Impact Abrasion Test (paragraph 27)	A maximum 30 mg/min at stated testing conditions	Based on observed film toughness plus tested abrasion resistance.

Generic Type	Data similar to that in Table 1	An example is System No. 26: Primer/bondcoat — aromatic isocyanate adhesive. Topcoat-elastomeric aromatic-aliphatic polyurethane.
Elongation: ASTM D 412-87 Die 'B' or 'C'	350 percent, minimum	
Recoating Time at 75 °F (23.9 °C)	0.33 hours, minimum, 72 hours, maximum	Overall range. Some systems will fall in between the overall range.
Minimum Curing Time after the final coat has been applied before immersion at 75 °F (23.9 °C)	1/3 day, minimum 7 days, maximum	Overall range. Some systems will fall in between the overall range.
Volume Solids:	56 percent, minimum	See "note" below.
VOC (as supplied)	406 g/l (3.4 lb/gal), maximum	See "note" below

Note: Primer/bond coats for elastomeric polyurethanes tend to be high in VOC. Most manufacturers contacted stated either that they could supply the same coatings at a lower VOC, or that they were working on new, lower VOC, primer/bond coats. The 406 g/l (3.4 lb/gal) figure was the highest of any elastomeric polyurethane topcoat tested. The same manufacturers stated that they either had available, or were developing, lower VOC elastomeric topcoats, as well.

77. Although half the systems had relatively small (ΔE^*_{ab}) color changes in the QUV-Prohesion test, all had next to no gloss retention. This indicates that where appearance above the waterline is important, a compatible good weathering topcoat may be necessary. The severity of the UVB-313 lamps on polyurethane coatings (paragraph 19) indicate field trials will be needed to establish the degree of topcoat aesthetic durability in a definitive manner.

78. None of the elastomeric polyurethane topcoats investigated require plural component spray. Some do, however, require adequately sized and powered pumps and other spraying equipment. The best application technique for one may not be suitable for another. Consequently, thorough attention to the manufacturers' instructions and to the entire application process is required for satisfactory performance of the coatings.

79. The total initial costs of the coating systems tested are higher than those of the systems tested for Baker and Beitelman (1992). This is not surprising, considering that a heavy (60 mils [1.5 mm]) topcoat of a costly coating material is being applied over a coating system similar to those in Baker and Beitelman (1992). Field experience will determine if a less frequent need for waterline coating repairs and an extended satisfactory service life will result in equal or lower life-cycle costs. Also, the development of better and more economical combinations of base and topcoats would have a favorable effect on costs.

80. The data acquired in this investigation provide control points for the performance recorded for the coating combinations and under the sets of conditions and film thicknesses in force at the time of testing. These control points will prove useful for future investigations of the effects of changing coating combinations, film thicknesses, conditions of testing, etc., for any of the coating systems in the investigation.

81. The systems were chosen for field testing based on laboratory performance data; however, once placed in the abrasive environment of the inland waterways, failures were noted. The failures observed ranged from localized delamination to absolute delamination of the entire polyurethane topcoat. In general, the gross adhesion failures were due to interface problems between the bond coats and the respective topcoats.

82. When attempting to adhere two unlike coatings such as an epoxy and a urethane, success is often impeded by the difficulty in manipulating the chemistry of one coating to accommodate that of another. Bond

coats are typically employed to cement the two coatings together, but they must be specifically developed to emulate the chemistry of both subordinate coatings. The bond coats used in each of the field tests were prescribed and formulated by the respective manufacturers to adhere the polyurethanes to an epoxy substrate. However, the extreme abrasion and impact that exists on the river creates an environment in which intercoat adhesion is easily destroyed. Until stronger adhesion can be effected between the polyurethane and the bond coat, polyurethanes will remain ineffective as a topcoat over epoxies in high abrasion areas such as tainter gates.

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APPENDIX A: TABLES AND FIGURES

Table 1. - Commercially available coatings systems tested

System No.	Components/minimum number of coats ( ) [1]	Visual color of topcoat	Application method for test panels - generic type [2]	Volume solids (percent) [3]	Target dry-film thickness (DFT)(mils) [4]	VOC content (g/L) [3]
Common basecoat (all systems)	Topcoat (2) Primer (1)	----- -----	MIL-P-24441/30 FISI type IV Haze Gray (epoxy) MIL-P-24441/29 FISO type IV Green Primer (epoxy)	66.0 67.0	6.0 3.0	340 340
25	Topcoat (1) Primer/tie coat (1)	Orange	Trowelled elastomeric aromatic-aliphatic polyurethane Brushed aromatic isocyanate adhesive	80.4 30.8	60.0 1.5	176 670
26	Topcoat (1) Primer/tie coat (1)	Orange	Sprayed elastomeric aromatic-aliphatic polyurethane Sprayed aromatic isocyanate adhesive	56.1 30.8	60.0 2.0	406 670
27	Topcoat (2) Primer/tie coat (1)	Med gray	Brushed elastomeric aromatic-aliphatic polyurethane Brushed isocyanate polyol	70.0 34.0	60.0 1.5	325 645
28	Topcoat (6)	Lt gray	Brushed elastomeric aromatic polyurethane	67.2	60.0	293
29	Topcoat (3)	Aqua	Brushed elastomeric aromatic polyurethane	68.0	60.0	290
30	Topcoat (3+) Primer/tie coat (1)	Lt blue	Brushed elastomeric aromatic moisture cure polyurethane Brushed moisture cure mixed aromatic isocyanate	70.0 53.0	60.0 1.0 to 2.0	265 418
31	Topcoat (4) Primer/tie coat (1)	Dk blue	Sprayed elastomeric aromatic polyurethane Sprayed isocyanate bonding primer (1 package)	70.0 12.5	60.0 2.0	299 574
32	Topcoat (1) Primer/tie coat (1)	Lt red	Trowelled elastomeric aliphatic polyurethane Sprayed isocyanate aromatic polyurethane adhesive (2 package)	100.0 30.0	60.0 2.0	Neg 574
33	Topcoat [5] (1)	Black	Squeegeed elastomeric aromatic asphalt polyurethane	90.0	60.0	78
34	Topcoat (3)	White	Sprayed elastomeric aliphatic polyurethane	66.0	60.0	300

Notes

1. Coating manufacturers' recommendations.
2. Method used on panels supplied by coatings manufacturers or method used on Reclamation-prepared panels.
3. Data supplied by coatings manufacturers.
4. Target dry-film thicknesses (DFTs) were 9 mils for the common basecoat and 60 mils for the elastomeric topcoats. Target DFTs above 69.0 (total) represent the use of a manufacturer's recommended primer/tie coat. The recommended target DFTs of these primer/tie coats are shown in this table.
5. Squeegee application on a flat surface. Three coats may be required for spray application on a vertical surface.

Table 2. - Coating systems data

System No.	Total target DFT (mils)[1]	No. of coats, min.[2] P	No. of coats, min.[2] T	Method of application	Elongation of topcoat (%)[7]	Topcoat tensile strength (psi)[7]	Topcoat tear strength (pli)[7]	Topcoat hardness (Shore A)[7]	Recoating time @ 75 °F min. - max. (hours)	Min. curing time @ 75 °F (days)[4]	Mixing ratio pkg A: pkg B (volume)[2]	Pot life @ 70 - 75 °F (hours)[2]	Est. cost per sq. ft. ($)[5]
Common Basecoat (all systems)	9	1	2	P - Brush, conv. or airless spray T - Brush, conv. or airless spray	-	-	-	-	P:3-24 T:3-24	-	P - 1:1 T - 1:1	P - 6.0 T - 6.0	1.14
25	70.5	1	1	P - Brush, conv. or airless spray T - Trowel-type	500	3,500	90	85	P:0.5-4 T:0.33-1	4	(A)(B)(C) P - 40 :1 :3 T - 5 :1	P - 4.0 T - 1.5	7.00 - 8.00
26	71.0	1	1	P - Brush, conv. or airless spray T - Conv. or airless spray	350	3,500	95	92	P:0.5-4 T:0.33-4	4	(A)(B)(C) P - 40 :1 :3 T - 1 :1	P - 4.0 T - 1.5	6.00
27	70.5	1	2	P - Brush, conv. or airless spray T - Brush, airless spray	300	1,500	225	75	P:0.5-24 T:2-72	4	P - 4:1 T - 1:1	P - 24.0 T - 1.0	4.00 - 6.00
28	69.0	(SP)[3]	6	T - Brush, conv. or airless spray	250	1,300	N/Av	70	T:6-48	7	T - 1:1	T - 2.5 (60 °F)	4.22
29	69.0	(SP)	3	T - Brush, airless spray	500	3,500	350	90	T:6-168	7	T - 1:4	T - 1.25	4.58
30	70.0-71.0	1	3+	P - Brush, conv. or airless spray T - Brush, conv. or airless spray	475	2,050	250	N/Av[6]	P:0.25-0.5 T:1-72	1/3	P - (1-pkg) T - (1-pkg)	P - N/A[8] T - N/A	2.50
31	71.0	1	4	P - Brush, conv. or airless spray T - Brush, airless spray	490	5,240	350	90	P:1-168 T:0.5-6	7	P - (1-pkg) T - 3:1	P - N/A T - 0.75	2.46
32	71.0	1	1	P - Brush, conv. or airless spray T - Trowel-type	500	3,200	300	82	P:1-24 T:16-96	7	P - 1:1 T - 5:1 (wt.)	P - 4.0 T - 0.75	1.75
33	69.0	(SP)	[9]1	T - Trowel, brush, roller, squeegee, conv. spray	350	570	118	52	T:firm-4	1	T - 9:1	T - 0.50	2.25
34	69.0	(SP)	3	T - Brush, roller, airless spray	400	2,400	350	85	T: <2 - 48 hrs	5	T - 1:1	T - 2.0	4.25

Notes

1. DFT = Dry-film thickness. The thickness given are the target DFTs. Target DFTs include the common basecoat (9 mils) plus the target DFTs of the primer/tie coats for the elastomers and/or the target DFT (60 mils) of the elastomeric topcoats. For actual DFTs, see the appropriate tables of testing results.
2. The minimum number of coats for the primer/tie coats and/or the elastomeric topcoats are those recommended by the manufacturers of the coatings. In no instance were fewer than the recommended number of coats applied to the testing panels. P = primer or primer/tie coat, T = elastomeric topcoat.
3. (SP) = Self-priming. The total number of coats for these coatings systems appear under the topcoat columns because they are "one-coating" systems.
4. The minimum curing times at an ambient temperature of 75 °F are for immersion service in either saltwater or freshwater. They are the minimum curing times required after the final coat has been applied. The manufacturers' advice and instructions must be followed for lower or higher temperatures, or if there are chemical constituents in the water other than those normally present in saltwater or freshwater.
5. The estimated costs per square foot which are given, were obtained from the manufacturers of the coating systems and are for information only. They include the costs of the coatings used and approximate application costs, but are exclusive of surface preparation. These costs are merely general approximations. Individual applications will require individual cost estimates and they may vary noticeable from those given.
6. N/Av = Not available.
7. The values of these properties were obtained from the manufacturer of the elastomeric topcoats. Details of the testing methods used are listed in Table 12.
8. N/A = Not applicable.
9. Squeegee on a flat surface. Three coats may be required for spray application on a vertical surface.

Table 3. - Immersion tests data - blistering and rusting

	Saltwater immersion					Fresh (deionized) water immersion				
System No. Panel No.	Average dry-film thickness (mils)	Initial blistering (hours) [3]	100 percent rusting in scribe lines (hours)[3]	Total hours completed	Blister size and frequency (completion) [1]	Average dry-film thickness (mils)	Initial blistering (hours) [3]	100 percent rusting in scribe lines (hours) [3]	Total hours completed	Blister size and frequency (completion) [1]
25-1	68.8	----------	167	3,160	----------	70.0	----------	167	3,160	----------
25-2	72.2	----------	167	3,160	----------	67.6	----------	167	3,160	----------
Average or comments:	70.5	----------	167	3,160	----------	68.8	----------	167	3,160	----------
26-1	103.2	----------	167	3,160	---------- [4]	104.6	----------	167	3,160	----------
26-2	104.6	----------	167	3,160	----------	104.6	----------	167	3,160	----------
Average or comments:	103.9	----------	167	3,160	----------	104.6	----------	167	3,160	----------
27-1	70.2	----------	167	3,508	---------- [4]	70.6	----------	167	3,508	----------
27-2	70.0	----------	167	3,508	----------	69.8	----------	167	3,508	----------
Average or comments:	70.1	----------	167	3,508	----------	70.2	----------	167	3,508	----------
28-1	70.0	1,645 [2]	167	3,160	9 No. 2	70.2	----------	167	3,160	----------
28-2	62.9	1,645 [2]	167	3,160	6 No. 2	69.4	----------	167	3,160	----------
Average or comments:	66.5	1,645 [2]	167	3,160	No. 2 on back 28-1 [3] N.B.O.B.28-2 [3]	69.8	----------	167	3,160	----------
29-1	70.2	----------	168	3,508	----------	69.9	----------	168	3,508	----------
29-2	69.8	----------	168	3,508	----------	69.6	----------	168	3,508	----------
Average or comments:	70.0	----------	168	3,508	----------	69.8	----------	168	3,508	----------
30-1	70.0	----------	165	3,176	----------	70.0	----------	165	3,176	----------
30-2	70.0	----------	165	3,176	----------	70.6	----------	165	3,176	----------
Average or comments:	70.0	----------	165	3,176	----------	70.3	----------	165	3,176	----------
31-1	63.6	----------	334	3,176	---------- [4]	62.2	----------	165	3,176	----------
31-2	62.6	----------	334	3,176	----------	63.0	----------	165	3,176	----------
Average or comments:	63.1	----------	334	3,176	----------	62.6	----------	165	3,176	----------
32-1	92.2	----------	334	3,176	---------- [4]	96.6	----------	165	3,176	----------
32-2	92.6	----------	334	3,176	----------	96.2	----------	165	3,176	----------
Average or comments:	92.4	----------	334	3,176	----------	96.4	----------	165	3,176	----------

Table 3. - Immersion tests data - blistering and rusting - Continued

	Saltwater immersion					Fresh (deionized) water immersion				
System No. Panel No.	Average dry-film thickness (mils)	Initial blistering (hours) [3]	100 percent rusting in scribe lines (hours)[3]	Total hours completed	Blister size and frequency (completion) [1]	Average dry-film thickness (mils)	Initial blistering (hours) [3]	100 percent rusting in scribe lines (hours) [3]	Total hours completed	Blister size and frequency (completion) [1]
33-1	71.4	----------	167	3,160	----------	69.5	----------	167	3,160	----------
33-2	69.2	----------	167	3,160	----------	71.6	----------	167	3,160	----------
Average or comments:	70.3	----------	167	3,160	----------	70.6	----------	167	3,160	----------
34-1	70.8	----------	167	3,160	----------	70.6	----------	167	3,160	----------
34-2	69.4	----------	167	3,160	----------	69.2	----------	167	3,160	----------
Average or comments:	70.1	----------	167	3,160	----------	69.9	----------	167	3,160	----------

Notes

1. Pictorial Standards of Coatings Defects and ASTM D 714-87. The largest number refers to the smallest blisters on a scale of 2 to 8 (2-large, 8-small).
2. N.B.O.B. = No blistering on back(s).
3. The numbers of hours recorded are the numbers of hours of exposure as of the time the panels were examined. The exact numbers of hours before blistering or rusting took place are unknown. However, in no instance would the numbers of hours be less than the recorded numbers of hours by more than 1 weeks' exposure time, approximately 164 to 168 hours.
4. These systems, Nos. 26, 27, 29, and 31, had "welts" rather than clearly distinguishable blisters. The true nature of these welts will be discovered after continued immersion.
5. System No. 28 did not "fail" in the usual sense. Destructive testing with a scalpel after the completion of the test revealed that the blisters were within the elastomeric topcoat system. There was no corrosion of the substrate below the blisters. For practical purposes, system No. 28 "passed" in that the corrosion resistance of the system remained intact.

Table 4. - Immersion tests data - color change (Illuminant C) [4]

System No. Panel No. SW or FW [1]	Average dry-film thickness (mils)	Hours of immersion before color was checked	CIE 1976 CIELAB L* a* b* color data [2]										Panel is continuing in immersion test? [5]	
			Before immersion			After immersion			Color difference					
			L*	a*	b*	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*ab [3]	Yes	No
25-1 SW	68.8	3,160	64.54	35.30	63.35	63.40	30.97	49.42	-1.14	-4.33	-13.93	14.63	X	
25-2 SW	72.2	3,160	64.32	36.31	63.78	62.34	33.74	53.82	-1.98	-2.57	-9.96	10.48	X	
Average:	70.5	3,160	64.43	35.81	63.57	62.87	32.36	51.62	-1.56	-3.45	-11.95	12.56		
25-1 FW	70.0	3,160	66.21	38.33	65.67	63.12	35.81	58.15	-3.09	-2.52	-7.52	8.51	X	
25-2 FW	67.6	3,160	65.73	36.80	65.46	58.62	30.56	49.68	-7.11	-6.24	-15.78	18.40	X	
Average:	68.8	3,160	65.97	37.57	65.57	60.87	33.19	53.92	-5.10	-4.38	-11.65	13.46		
26-1 SW	103.2	3,160	54.68	45.22	51.78	57.53	45.02	46.83	2.85	-0.20	-4.95	5.72	X	
26-2 SW	104.6	3,160	55.45	44.93	49.84	57.79	45.66	48.05	2.34	0.73	-1.79	3.04	X	
Average:	103.9	3,160	55.07	45.08	50.81	57.66	45.34	47.44	2.60	0.27	-3.37	4.38		
26-1 FW	104.6	3,160	55.08	45.15	51.32	57.27	43.43	41.65	2.19	-1.72	-9.67	10.06	X	
26-2 FW	104.6	3,160	54.79	44.96	51.72	57.22	45.63	45.93	2.43	0.67	-5.79	6.31	X	
Average:	104.6	3,160	54.94	45.06	51.52	57.25	44.53	43.79	2.31	-0.53	-7.73	8.19		
27-1 SW	70.2	3,508	59.46	-4.78	2.13	54.37	-0.24	11.57	-5.09	4.54	9.44	11.65	X	
27-2 SW	70.0	3,508	59.74	-4.69	1.83	59.12	-1.06	7.33	-0.62	3.63	5.50	6.62	X	
Average:	70.1	3,508	59.60	-4.74	1.98	56.75	-0.65	9.45	-2.86	4.09	7.47	9.14		
27-1 FW	70.4	3,508	59.07	-4.69	1.68	55.41	-1.20	13.73	-3.66	3.49	12.05	13.07	X	
27-2 FW	70.0	3,508	59.85	-4.80	2.14	57.00	-0.77	14.70	-2.85	4.03	12.56	13.50	X	
Average:	70.2	3,508	59.46	-4.75	1.91	56.21	-0.99	14.22	-3.26	3.76	12.31	13.29		
28-1 SW	70.0	3,160	73.85	-1.46	2.85	72.22	-1.45	11.22	-1.63	0.01	8.37	8.53		X
28-2 SW	62.9	3,160	73.21	-1.45	2.85	70.63	-0.92	14.91	-2.58	0.53	12.06	12.34		X
Average:	66.5	3,160	73.53	-1.46	2.85	71.43	-1.19	13.07	-2.11	0.27	10.22	10.44		
28-1 FW	70.2	3,160	73.73	-1.44	2.90	70.77	-1.80	14.71	-2.96	-0.36	11.81	12.18	X	
28-2 FW	69.4	3,160	73.53	-1.43	2.96	70.35	-1.88	13.85	-3.18	-0.45	10.89	11.35	X	
Average:	69.8	3,160	73.63	-1.44	2.93	70.56	-1.84	14.28	-3.07	-0.41	11.35	11.77		
29-1 SW	70.2	3,508	74.79	-21.15	-11.22	68.07	-12.22	8.52	-6.72	8.93	19.74	22.68	X	
29-2 SW	69.8	3,508	74.44	-20.92	-11.07	66.82	-12.05	11.78	-7.62	8.87	22.85	25.67	X	
Average:	70.0	3,508	74.62	-21.04	-11.15	67.45	-12.14	10.15	-7.17	8.90	21.30	24.18		
29-1 FW	69.9	3,508	74.89	-21.38	-11.20	66.65	-14.12	14.25	-8.24	7.26	25.45	27.72	X	
29-2 FW	69.6	3,508	74.04	-21.34	-11.44	67.10	-14.41	8.60	-6.94	6.93	20.04	22.31	X	
Average:	69.8	3,508	74.47	-21.36	-11.32	66.88	-14.27	11.43	-7.59	7.10	22.75	25.02		
30-1 SW	70.0	3,176	72.07	-5.00	-29.76	68.24	-8.73	-10.17	-3.83	-3.73	19.59	20.31	X	
30-2 SW	70.0	3,176	72.45	-4.97	-28.88	70.25	-8.28	-15.21	-2.20	-3.31	13.67	14.24	X	
Average:	70.0	3,176	72.26	-4.99	-29.32	69.25	-8.51	-12.69	-3.02	-3.52	16.63	17.28		
30-1 FW	70.0	3,176	71.71	-4.84	-29.65	64.44	-9.72	4.74	-7.27	-4.88	34.39	35.49	X	
30-2 FW	70.6	3,176	72.50	-4.80	-28.91	61.87	-7.95	13.26	-10.63	-3.15	42.17	43.60	X	
Average:	70.3	3,176	72.11	-4.82	-29.28	63.16	-8.84	9.00	-8.95	-4.02	38.28	39.55		

Table 4. - Immersion tests data - color change (Illuminant C) [4] - Continued

System No. Panel No. SW or FW [1]	Average dry-film thickness (mils)	Hours of immersion before color was checked	CIE 1976 CIELAB L* a* b* color data [2]										Panel is continuing in immersion test? [5]	
			Before immersion			After immersion			Color difference					
			L*	a*	b*	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*ab [3]	Yes	No
31-1 SW	63.3	3,176	38.79	10.45	-48.46	40.10	6.34	-41.58	1.31	-4.11	6.88	8.12	X	
31-2 SW	57.6	3,176	40.50	9.89	-47.45	41.14	7.01	-42.80	0.64	-2.88	4.65	5.51	X	
Average:	60.5	3,176	39.65	10.17	-47.96	40.62	6.68	-42.19	0.98	-3.50	5.77	6.82		
31-1 FW	62.2	3,176	39.27	10.30	-48.05	40.33	-3.36	-21.50	1.08	-13.66	26.55	29.88	X	
31-2 FW	63.0	3,176	38.86	10.44	-48.47	40.38	-3.29	-20.85	1.52	-13.73	27.62	30.88	X	
Average:	62.6	3,176	39.07	10.37	-48.26	40.36	-3.33	-21.18	1.30	-13.70	27.09	30.38		
32-1 SW	92.2	3,176	47.62	54.07	46.02	48.81	52.51	41.46	1.19	-1.56	-4.56	4.96	X	
32-2 SW	92.6	3,176	47.76	53.36	44.62	49.75	48.94	36.14	1.99	-4.42	-8.48	9.77	X	
Average:	92.4	3,176	47.69	53.72	45.32	49.28	50.73	38.80	1.59	-2.99	-6.52	7.37		
32-1 FW	96.6	3,176	47.82	53.61	44.43	49.14	47.30	33.36	1.32	-6.31	-11.07	12.81	X	
32-2 FW	96.2	3,176	47.72	53.86	45.61	49.53	46.89	32.75	1.81	-6.97	-12.86	14.74	X	
Average:	96.4	3,176	47.77	53.74	45.02	49.34	47.10	33.06	1.57	-6.64	-11.97	13.78		
33-1 SW	71.4	3,160	25.37	0.17	-0.68	27.46	0.13	1.86	2.09	-0.04	2.54	3.29	X	
33-2 SW	69.2	3,160	23.99	0.24	-0.45	31.17	-0.13	0.78	7.18	-0.37	1.23	7.29	X	
Average:	70.3	3,160	24.68	0.21	-0.57	29.32	0.00	1.32	4.64	-0.21	1.89	5.29		
33-1 FW	69.5	3,160	24.11	0.24	-0.48	29.70	0.14	-1.83	5.59	-0.10	-1.35	5.75	X	
33-2 FW	71.6	3,160	22.82	0.15	-0.29	30.75	-0.04	-1.69	7.93	-0.19	-1.40	8.05	X	
Average:	70.6	3,160	23.47	0.20	-0.39	30.23	0.05	-1.76	6.76	-0.15	-1.38	6.90		
34-1 SW	70.8	3,160	95.94	-0.80	2.11	72.50	14.20	52.76	-23.44	15.00	50.65	57.79	X	
34-2 SW	69.4	3,160	96.09	-0.79	2.13	92.96	-0.79	10.85	-3.13	0.00	8.72	9.26	X	
Average:	70.1	3,160	96.02	-0.80	2.12	82.73	6.71	31.81	-13.29	7.50	29.69	33.53		
34-1 FW	70.6	3,160	94.42	-0.80	2.16	78.50	2.80	33.07	-15.52	3.60	30.91	34.77	X	
34-2 FW	69.2	3,160	96.00	-0.80	2.09	80.69	3.23	30.99	-15.31	4.03	28.90	32.95	X	
Average:	69.9	3,160	95.21	-0.80	2.13	79.60	3.02	32.03	-15.42	3.82	29.91	33.86		

Notes

1. SW = saltwater, FW = fresh (deionized) water.
2. The CIE 1976 CIELAB L* a* b* color data system is based on a three-dimensional color mapping system. The L*, or lightness axis is perpendicular to the +a* (red), -a* (green), +b* (yellow), and -b* (blue) axes.
3. The total color difference, ΔE^*_{ab}, was calculated using the method given in ASTM D 2244-85. The equation used to calculate ΔE^*_{ab} is: $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$
4. For a discussion of illuminant C, consult note No. 1 of table 5.
5. Panels which did not blister during the basic immersion period, which coincided with the "Hours of immersion before color was checked" column, are being continued in the saltwater and fresh (deionized) water immersion tests.

Table 5. - QUV-Prohesion accelerated weathering test data - chalking, rusting (scribe lines), color change (3,000 hours)

System No. panel No.	Illuminant[1]	Average DFT (mils)	Initial chalking (hours)[2,6]	100 percent rusting in scribe lines (hours)[1]	Total hours completed	Chalk rating (completion)[3]	CIE 1976 CIELAB L*a*b* color data[4]									
							Before exposure			After exposure			Color change			
							L*	a*	b*	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE^*_{ab}[5]
25-1	C	72.6	--	167	3,008	10	62.96	32.99	61.39	58.25	35.49	56.54	-4.71	2.50	-4.85	7.21
25-2	C	74.2	--	167	3,008	10	65.27	35.91	64.32	57.20	33.19	54.70	-8.07	-2.72	-9.62	12.85
Average:	C	73.4	--	167	3,008	10	64.12	34.45	62.86	57.73	34.34	55.62	-6.39	-0.11	-7.24	10.03
25-1	D65	72.6	--	167	3,008	10	65.84	38.80	65.07	58.38	37.12	56.61	-7.46	-1.68	-8.46	11.40
25-2	D65	74.2	--	167	3,008	10	64.78	36.17	62.55	57.71	34.96	55.44	-7.07	-1.21	-7.11	10.10
Average:	D65	73.4	--	167	3,008	10	65.31	37.49	63.81	58.05	36.04	56.03	-7.27	-1.45	-7.79	10.75
26-1	C	101.8	501	167	3,008	8	54.44	44.91	51.63	58.45	40.89	43.16	4.01	-4.02	-8.47	10.20
26-2	C	108.4	501	167	3,008	8	54.84	45.13	52.14	59.09	41.57	42.58	4.25	-3.56	-9.56	11.05
Average:	C	105.1	501	167	3,008	8	54.64	45.02	51.89	58.77	41.23	42.87	4.13	-3.79	-9.02	10.63
26-1	D65	101.8	501	167	3,008	8	54.49	45.86	51.30	58.71	42.67	44.29	4.22	-3.19	-7.01	8.78
26-2	D65	108.4	501	167	3,008	8	54.92	46.21	52.02	59.50	43.16	43.60	4.58	-3.05	-8.42	10.06
Average:	D65	105.1	501	167	3,008	8	54.71	46.04	51.66	59.11	42.92	43.95	4.40	-3.12	-7.72	9.42
27-1	C	70.6	500	167	3,348	8	60.04	-4.82	2.12	63.90	-1.38	1.77	3.86	3.44	-0.35	5.18
27-2	C	69.8	500	167	3,348	8	59.24	-4.69	1.91	63.21	-1.14	3.27	3.97	3.55	1.36	5.50
Average:	C	70.2	500	167	3,348	8	59.64	-4.76	2.02	63.56	-1.26	2.52	3.92	3.50	10.51	5.34
27-1	D65	70.6	500	167	3,348	8	60.10	-0.55	-1.20	64.16	-1.35	1.82	4.06	-0.80	3.02	5.12
27-2	D65	69.8	500	167	3,348	8	59.84	-0.53	-1.41	63.67	-1.02	3.23	3.83	-0.49	4.64	6.04
Average:	D65	70.2	500	167	3,348	8	59.97	-0.54	-1.31	63.92	-1.19	2.53	3.95	-0.65	3.83	5.58
28-1	C	71.0	1,502	167	3,008	6	73.76	-1.47	2.90	75.25	-1.43	9.38	1.49	0.04	6.48	6.65
28-2	C	70.8	1,502	167	3,008	6	73.55	-1.48	2.92	70.75	-0.39	11.78	-2.80	1.09	8.86	9.36
Average:	C	70.9	1,502	167	3,008	6	73.66	-1.48	2.91	73.00	-0.91	10.58	-0.66	0.57	7.67	8.01
28-1	D65	71.0	1,502	167	3,008	6	73.78	-1.47	2.88	75.70	-1.13	9.19	1.92	0.04	6.31	6.60
28-2	D65	70.8	1,502	167	3,008	6	73.57	-1.45	2.90	71.10	-0.02	11.36	-2.47	1.09	8.46	8.93
Average:	D65	70.9	1,502	167	3,008	6	73.68	-1.46	2.89	73.40	-0.58	10.28	-0.28	0.57	7.39	7.77
29-1	C	69.4	836	168	3,348	8	74.27	-21.38	-10.99	72.14	-13.94	-9.90	-2.13	7.44	1.09	7.82
29-2	C	69.0	836	168	3,348	8	74.71	-21.34	-11.41	71.96	-14.63	-11.30	-2.75	6.71	0.11	7.25
Average:	C	69.2	836	168	3,348	8	74.49	-21.36	-11.20	72.05	-14.29	-10.60	-2.44	7.08	0.60	7.54
29-1	D65	69.4	836	168	3,348	8	74.17	-16.90	-15.09	72.34	-14.43	-9.84	-1.83	2.47	5.25	6.08
29-2	D65	69.0	836	168	3,348	8	74.85	-16.65	-15.76	72.64	-15.31	-11.15	-2.21	1.34	4.61	5.29
Average:	D65	69.2	836	168	3,348	8	74.51	-16.78	-15.43	72.49	-14.87	-10.50	-2.02	1.91	4.93	5.69
30-1	C	70.4	165	165	3,031	8	71.32	-4.88	-28.40	69.76	-10.75	-10.27	-1.56	-5.87	18.13	19.12
30-2	C	70.4	165	165	3,031	8	71.31	-5.11	-29.53	70.36	-11.01	-11.59	-0.95	-5.90	17.94	18.91
Average:	C	70.4	165	165	3,031	8	71.32	-5.00	-28.97	70.06	-10.88	-10.93	-1.26	-5.89	18.04	19.02

Table 5. - QUV - Prohesion accelerated weathering test data - chalking, rusting (scribe lines), color change (3,000 hours) - Continued

System No. panel No.	Illuminant[1]	Average DFT (mils)	Initial chalking (hours)[2,6]	100 percent rusting in scribe lines (hours)[1]	Total hours completed	Chalk rating (completion)[3]	CIE 1976 CIELAB L*a*b* color data[4]									
							Before exposure			After exposure			Color change			
							L*	a*	b*	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE^*_{ab}[5]
30-1	D65	70.4	165	165	3,031	8	71.34	-6.04	-28.40	70.15	-11.33	-10.35	-1.19	-5.29	18.05	18.85
30-2	D65	70.4	165	165	3,031	8	71.33	-6.31	-29.67	70.71	-11.60	-11.59	-0.62	-5.29	18.08	18.85
Average:	D65	70.4	165	165	3,031	8	71.34	-6.18	-29.04	70.43	-11.47	-10.97	-0.91	-5.29	18.07	18.85
31-1	C	60.4	1,836	165	3,031	10	38.62	10.55	-48.59	41.86	2.55	-36.80	3.24	-8.00	11.79	14.61
31-2	C	60.0	1,836	165	3,031	10	38.86	10.63	-48.26	42.50	2.00	-35.11	3.64	-8.63	13.15	16.14
Average:	C	60.2	1,836	165	3,031	10	38.74	10.59	-48.43	42.18	2.28	-35.96	3.44	-8.32	12.47	15.38
31-1	D65	60.4	1,836	165	3,031	10	38.67	8.50	-48.56	42.21	1.18	-36.77	3.54	-7.32	11.79	14.32
31-2	D65	60.0	1,836	165	3,031	10	38.78	8.60	48.35	42.50	0.59	-35.33	3.72	-8.01	13.02	15.73
Average:	D65	60.2	1,836	165	3,031	10	38.73	8.55	48.46	42.36	0.89	-36.05	3.63	-7.67	12.41	15.03
32-1	C	68.6	501	165	3,031	10	47.76	53.35	45.06	50.97	40.82	28.75	3.21	-12.53	-16.31	20.82
32-2	C	113.8	501	165	3,031	10	47.85	54.01	46.11	51.91	38.15	29.07	4.06	-15.86	-17.04	23.63
Average:	C	91.2	501	165	3,031	10	47.81	53.68	45.59	51.44	39.49	28.91	3.64	-14.20	-16.68	22.23
32-1	D65	68.6	501	165	3,031	10	47.87	56.39	42.05	51.27	42.04	29.19	3.40	-14.35	-12.86	19.57
32-2	D65	113.8	501	165	3,031	10	47.90	57.21	44.12	52.30	38.86	29.07	4.40	-18.35	-15.05	24.14
Average:	D65	91.2	501	165	3,031	10	47.89	56.80	43.09	51.79	40.45	29.13	3.90	-16.35	-13.96	21.86
33-1	C	88.6	167	167	3,008	10	22.76	0.18	-0.47	23.89	0.26	0.45	1.13	0.08	0.92	1.46
33-2	C	79.2	167	167	3,008	10	22.93	0.34	-0.45	19.32	0.50	0.68	-3.61	0.16	1.13	3.79
Average:	C	83.9	167	167	3,008	10	22.85	0.26	-0.46	21.61	0.38	0.57	-1.24	0.12	1.03	2.63
33-1	D65	88.6	167	167	3,008	10	22.95	0.32	-0.61	23.95	0.26	0.54	1.00	-0.06	1.15	1.53
33-2	D65	79.2	167	167	3,008	10	23.32	0.09	-0.44	20.05	0.44	0.67	-3.27	0.35	1.11	3.47
Average:	D65	83.9	167	167	3,008	10	23.14	0.21	-0.53	22.00	0.35	0.61	-1.14	0.15	1.13	2.50
34-1	C	65.6	167	167	3,008	8	96.00	-0.90	2.56	95.74	-0.53	5.92	-0.26	0.37	3.36	3.39
34-2	C	68.4	167	167	3,008	8	96.09	-0.79	2.07	96.15	-0.66	5.75	0.06	0.13	3.68	3.68
Average:	C	67.0	167	167	3,008	8	96.05	-0.85	2.32	95.95	-0.60	5.84	-0.10	0.25	3.52	3.54
34-1	D65	65.6	167	167	3,008	8	95.93	-0.85	2.50	96.14	-0.36	6.11	0.21	0.49	3.61	3.65
34-2	D65	68.4	167	167	3,008	8	96.16	-0.80	2.06	96.48	-0.50	5.81	0.32	0.30	3.75	3.78
Average:	D65	67.0	167	167	3,008	8	96.05	-0.83	2.28	96.31	-0.43	5.96	0.27	0.40	3.68	3.72

Notes

1. The color data obtained from the Minolta CR-200b can be recorded for two illuminants: C and D65. CIE standard illuminant C simulates a cloudy day and CIE standard illuminant D65 simulates a bright day. The color temperature of illuminant D65 is lower than illuminant C, and the colors measure "cooler" when D65 is used. Illuminant C has been the most widely used standard illuminant since 1931. However, illuminant D65 is coming into wider use. For this reason and to provide a comparison of the colors under different illuminant conditions, CIE standard illuminant D65 is included in this table along with CIE Standard Illuminant C.
2. Initial chalking is the first appearance of apparent definite chalking. Color fade, although an indications that chalking may be occurring, was not recorded as chalking.
3. Pictorial Standards of Coating Defects and ASTM D 659-86. A rating of 2 is very heavy chalking and a rating of 10 is no chalking on the rating scale of 2, 4, 6, 8, and 10.
4. For an explanation of the CIE 1976 CIELAB L*a*b* Color Data System, consult note No. 2 of table 4.
5. For an explanation of the total difference, ΔE^*_{ab}, consult note No. 3 of table 4.
6. The numbers of hours recorded are the numbers of hours of exposure as of the time the panels were examined. The exact number of hours before initial chalking or 100 percent rusting in the scribe lines took place are unknown. However, the numbers of hours would not be less by more than 1 week exposure time, approximately 164 to 168 hours.

Table 6. - QUV-Prohesion accelerated weathering test (blistering and 60° gloss)

System No. Panel No.	Average DFT (mils)	Initial gloss	Final gloss	Retained gloss (percent)	Initial blistering (hours) [1,4]	Blister size and frequency (completion) [3]
25-1	72.6	1.5	1.1	73.3	----------	----------
25-2	74.2	2.1	1.0	47.6	----------	----------
Average	73.4	1.8	1.1	60.5	----------	----------
26-1	101.8	29.8	0.9	3.0	----------	----------
26-2	108.4	31.5	1.0	3.2	----------	----------
Average:	105.1	30.7	1.0	3.1	----------	----------
27-1	70.6	15.4	0.9	5.8	----------	----------
27-2	69.8	20.6	1.0	4.9	----------	----------
Average:	70.2	18.0	1.0	5.4	----------	----------
28-1	71.0	66.8	1.4	2.1	----------	----------
28-2	70.8	62.6	1.2	1.9	----------	----------
Average:	70.9	64.7	1.3	2.0	----------	----------
29-1	69.4	35.7	1.0	2.8	----------	----------
29-2	69.0	35.4	1.0	2.8	----------	----------
Average:	69.2	35.6	1.0	2.8	----------	----------
30-1	70.4	48.4	2.0	4.1	2,340 [1]	4 No. 2
30-2	70.4	56.8	2.9	5.1	2,340	[7 No. 2] 30-2
Average	70.4	52.6	2.5	4.6	2,340	[1 No. 4] 30-2
31-1	60.4	79.6	1.6	2.0	----------	----------
31-2	60.0	64.0	2.1	3.3	2,508	3 No. 2
Average:	60.2	71.8	1.9	2.7	----------	----------
32-1	68.6	74.9	1.6	2.1	----------	----------
32-2	113.8	76.0	2.0	2.6	----------	----------
Average:	91.2	75.5	1.8	2.4	----------	----------
33-1	88.6	68.7	0.8	1.2	----------	----------
33-2	79.2	63.4	0.4	0.6	----------	----------
Average:	83.9	66.1	0.6	0.9	----------	----------
34-1	65.6	44.1	2.7	6.1	2,343	5 No. 2
34-2	68.4	75.5	3.3	4.4	2,343	4 No. 2
Average:	67.0	59.8	3.0	5.3	2,343	----------

Notes

1. The numbers of hours recorded are the number of hours of exposure as of the time the panels were examined. The exact numbers of hours before initial blistering took place are unknown. However, the numbers of hours would not be less by more than 1 weeks' exposure time, approximately 164 to 168 hours.
2. Although the panels listed are the ones which exhibited unmistakable blistering, all panels had rust creep of at least 1/2 to 3/4 inch (12.7 to 19.1 mm) at the top "V" of the intersections of the scribe lines.
3. Pictorial Standards of Coatings Defects and ASTM D 714-87. The largest number refers to the smallest blisters on a scale of 2 to 8 (2-large, 8-small).
4. Please refer to table 5 for total hours completed.

Table 7. - Pull-off (elcometer) adhesion test data, average of three readings

System No.	DFT (mils)	Average pull-off adhesion		Description of adhesive failure (Average of all "pulls")
		lb/in²	kPa	
25	71.0	[1]205	1,413	35 percent to topcoat primer 65 percent to epoxy topcoat
26	100.0	567	3,909	1 percent to epoxy primer 2 percent intracoat (topcoat) 97 percent to topcoat primer
27	69.4	333	2,296	100 percent intercoat (topcoat)
28	72.0	477	3,288	18 percent at glue line 25 percent glue line and topcoat 57 percent intercoat (topcoat)
29	69.0	512	3,530	7 percent glue line and topcoat 93 percent glue line
30	68.4	320	2,206	2 percent to substrate 3 percent to epoxy primer 95 percent to epoxy topcoat
31	61.8	240	1,655	9 percent to epoxy primer 10 percent epoxy topcoat and topcoat primer 14 percent intracoat (epoxy topcoat) 67 percent to topcoat primer
32	98.0	570	3,930	35 percent glue line 65 percent glue line and topcoat
33	68.6	510	3,516	6 percent intracoat (epoxy primer) 12 percent glue line 22 percent to epoxy topcoat 60 percent intracoat (topcoat)
34	71.0	500	3,447	15 percent intracoat (epoxy primer) 15 percent glue line and topcoat 23 percent glue line 47 percent epoxy topcoat

Notes

1. Average of two "pulls." The remaining systems' averages are of three "pulls."

Table 8. - One-inch Mandrel bend test data

System No. (one panel tested)	Average dry-film thickness (mils)	Description of convex immediate bending area
25	73.6	NC [1]
26	106.8	NC
27	71.2	NC
28	71.2	NC
29	71.4	NC
30	69.6	NC
31	59.6	NC
32	96.2	NC
33	63.6	NC
34	68.4	NC

Notes

1. NC = No cracking or loss of adhesion.

Table 9. - Brookfield viscosity profile data [conducted at 76 to 78 °F (24.4 to 25.6 °C)]

System No.	Stated pot life (hours)	RVT spindle No.	RPM	Elapsed time in minutes[1] (viscosities listed beneath in centipoises)[2] 15	30	45	60	75	90	105	120	135	Remarks
25	1.50 (trowel)	7	0.5	3.20×10^6 (a)	5.76×10^6	8.00×10^6 (a)	(b)		(c)				(a) "Ramp" beyond the range of the viscometer (b) Off-scale. Still fluid, but not trowellable. (c) Set-up
26	1.50	5	0.5	98.40×10^3	100.00×10^3	103.00×10^3							"Short" and not applicable at 1.5 hours.
			1.0			57.60×10^3							
			2.5			26.90×10^3							
			5.0			15.40×10^3							
			10.0			9.16×10^3							
			20.0			5.70×10^3							
			50.0			3.40×10^3							
			100.0			2.37×10^3							
			50.0			3.36×10^3							
			20.0			5.75×10^3							
			10.0			9.00×10^3							
			5.0			14.90×10^3							
			2.5			25.10×10^3							
			1.0			52.40×10^3							
			0.5			94.40×10^3	102.00×10^3	113.00×10^3	118.00×10^3				
27	1.00 (spray) 2.00 (brush or roll)	3	0.5	23.60×10^3	26.80×10^3								Not sprayable at 1.50 hours. Still somewhat brushable at 2.00 hours.
			1.0		16.00×10^3								
			2.5		7.22×10^3								
			5.0		4.44×10^3								
			10.0		2.54×10^3								
			20.0		1.47×10^3								
			10.0		2.09×10^3								
			5.0		3.20×10^3								
			2.5		5.20×10^3								
			1.0		10.50×10^3								
			0.5		19.00×10^3	22.00×10^3	26.40×10^3	28.00×10^3	28.40×10^3	16.00×10^3	20.20×10^3		
28	2.50 (60 °F)	6	0.5	496.00×10^3	344.00×10^3	336.00×10^3	360.00×10^3						Skinned over on top, too thick to spray or brush at 2.0 hours.
			1.0				224.00×10^3						
			2.5				120.00×10^3						
			5.0				80.00×10^3						
			10.0				57.00×10^3						
			20.0				45.80×10^3						
			50.0				22.80×10^3						
			100.0				14.50×10^3						
			50.0				15.70×10^3						
			20.0				19.40×10^3						
			10.0				25.20×10^3						
			5.0				36.00×10^3						
			2.5				51.20×10^3						
			1.0				128.00×10^3						
			0.5				312.00×10^3	560.00×10^3	768.00×10^3	872.00×10^3	976.00×10^3		

Table 9. - Brookfield viscosity profile data [conducted at 76 to 78 °F (24.4 to 25.6 °C)] - Continued

System No.	Stated pot life (hours)	RVT spindle No.	RPM	Elapsed time in minutes[1] (viscosities listed beneath in centipoises)[2]									Remarks
				15	30	45	60	75	90	105	120	135	
29	1.25	4	0.5	117.00 x 10^3	132.00 x 10^3								
			1.0		75.40 x 10^3								
			2.5		35.20 x 10^3								
			5.0		20.40 x 10^3								
			10.0		12.20 x 10^3								
			20.0		7.80 x 10^3								
			10.0		11.40 x 10^3								
			5.0		17.80 x 10^3								
			2.5		29.60 x 10^3								
			1.0		60.60 x 10^3								
			0.5		108.00 x 10^3	118.00 x 10^3	142.00 x 10^3	131.00 x 10^3 (d)					(d) End of ramp. Not sprayable, but brushable at 1.25 hours.
30	N/A (26% R.H.)	3	0.5	10.40 x 10^3									
		2	0.5		10.90 x 10^3	11.10 x 10^3	11.50 x 10^3						
			1.0				11.20 x 10^3						
			2.5				10.80 x 10^3						
			1.0				10.60 x 10^3						
			0.5				11.00 x 10^3	12.30 x 10^3	13.60 x 10^3	15.00 x 10^3	22.4 x 10^3	66.40 x 10^3	Thick skin at surface. Below surface brushable and borderline sprayable at 2.25 hours.
31	0.75	1	0.5	0.88 x 10	0.96 x 10^3								
			1.0		0.95 x 10^3								
			2.5		0.94 x 10^3								
			5.0		0.95 x 10^3								
			10.0		0.99 x 10								
			5.0		1.01 x 10^3								
			2.5		1.03 x 10^3								
			1.0		1.05 x 10^3								
			0.5		1.14 x 10^3	1.72 x 10^3	3.08 x 10^3	5.84 x 10^3	12.2 x 10^3				Still thin, sprayable at 1.00 hours. Thick and not sprayable or brushable at 1.50 hours.
32	0.75	3	0.5	20.40 x 10^3	26.00 x 10^3								
			1.0		27.10 x 10^3								
			2.5		28.00 x 10^3								
			1.0		29.10 x 10^3								
			0.5		30.20 x 10^3	110.00 x 10^3	200.00 x 10^3						Heavy and close to its limit, but fluid at 0.75 hours. Still self-levelling at 1.00 hours.
33	0.50	6	0.5	226.00 x 10^3									
			1.0	203.00 x 10^3									
			2.5	153.00 x 10^3									
			5.0	121.00 x 10^3									
			10.0	96.40 x 10^3									
			5.0	124.00 x 10^3									
			2.5	171.00 x 10^3									
			1.0	243.00 x 10^3									
			0.5	354.00 x 10^3	860.00 x 10^3								Thick and not useable after 0.50 hours.

Table 9. - Brookfield viscosity profile data [conducted at 76 to 78 °F (24.4 to 25.6 °C)] - Continued

System No.	Stated pot life (hours)	RVT spindle No.	RPM	Elapsed time in minutes[1] (viscosities listed beneath in centipoises)[2]									Remarks
				15	30	45	60	75	90	105	120	135	
34	2.00	2	0.5	12.20×10^3	11.20×10^3	10.70×10^3	10.70×10^3						
			1.0				6.92×10^3						
			2.5				4.16×10^3						
			5.0				2.88×10^3						
			10.0				2.00×10^3						
			20.0				1.39×10^3						
			10.0				1.64×10^3						
			5.0				2.18×10^3						
			2.5				3.04×10^3						
			1.0				5.08×10^3						
			0.5				8.08×10^3	9.20×10^3	9.76×10^3	10.10×10^3	8.08×10^3 (e)		(e) End of ramp. Fairly thin. Still sprayable or brushable after 2.00 hours.

Notes

1. The Brookfield viscometer was run continuously. There were no rest periods at the end of the "ramps."
2. Centipoises x 10^{-3} = Pa's.
3. Viscosity data was obtained on the unthinned elastomeric topcoats. Thinning, following only manufacturer's recommendations, will extend the workable pot lives of coatings intended to be thinned for applications and lower their viscosities at a given temperature.

Table 10. - Blasting media impact abrasion test data

System No.	Total DFT (mils)	Initial weight (grams)	Ending weight (grams)	Total loss (milligrams)	Length of test (minutes)[1]	Milligrams loss per minute
25	73.8	128.9055	128.4902	415.3	30	13.8
26	114.2	144.5170	143.6782	838.8	30	28.0
27	69.6	134.9580	133.9310	1,027.0	5 + 45 seconds	178.6
28	72.4	137.9920	136.9785	1,013.5	13 + 30 seconds	75.1
29	74.8	133.2660	132.0770	1,189.0	30	39.6
30	68.2	126.7045	126.1455	559.0	30	18.6
31	79.0	125.6335	125.2320	401.5	30	13.4
32	98.8	143.7020	143.4790	223.0	30	7.4
33	102.6	124.9970	124.3405	656.5	30	21.9
34	71.4	126.6490	126.0706	578.4	9 + 15 seconds	62.5
Epoxy control	17.2	90.0885	89.6484	440.1	17 seconds	1,553.5

Notes

1. Thirty minutes was the maximum testing period on panels which had not been abraded to the epoxy basecoat or partially to the substrate. As the data indicate, the time required to penetrate the approximately 9 mils total DFT epoxy basecoat would have been relatively short.

Table 11a. - Summary of test data - average values for each coatings systems

		Saltwater immersion			Fresh (deionized) water immersion			QUV-Prohesion accelerated weathering						Pull-off adhesion	
System No.	Total target DFT (mils)[1]	Initial blistering (hours)[4]	Total hours completed	Total color difference (ΔE^*_{ab})[2]	Initial blistering (hours)[4]	Total hours completed	Total color difference (ΔE^*_{ab})[2]	Initial blistering (hours)[4]	Total hours completed	Chalk rating (completion)[3]	60° gloss retained (percent)	Total color difference (ΔE^*_{ab})[2]	Undercutting over 1/8 inch at the top "V" scribe intersection	Control panel lb/in²	Control panel kPa
25	70.5	---------	3,160	12.56	---------	3,160	13.46	---------	3,008	10	60.5	10.03	Yes	205	1,413
26	71.0	---------	3,160	4.38	---------	3,160	8.19	---------	3,008	8	3.1	10.63	Yes	567	3,909
27	70.5	---------	3,508	9.14	---------	3,508	13.29	---------	3,348	8	5.4	5.34	Yes	333	2,296
28	69.0	1,645	3,160	10.44	---------	3,160	11.77	---------	3,008	6	2.0	8.01	Yes	477	3,288
29	69.0	---------	3,508	24.18	---------	3,508	25.02	---------	3,348	8	2.8	7.54	Yes	512	3,530
30	70.0 to 71.0	---------	3,176	17.28	---------	3,176	39.55	2,340	3,031	8	4.6	19.02	Yes	320	2,206
31	71.0	---------	3,176	6.82	---------	3,176	30.38	2,508	3,031	10	2.7	15.38	Yes	240	1,655
32	71.0	---------	3,176	7.37	---------	3,176	13.78	---------	3,031	10	2.4	22.23	Yes	570	3,930
33	69.0	---------	3,160	5.29	---------	3,160	6.90	---------	3,008	10	0.9	2.63	Yes	510	3,516
34	69.0	---------	3,160	33.53	---------	3,160	33.86	2,543	3,008	8	5.3	3.54	Yes	500	3,447

Notes

1. The values or information in these columns were supplied by the manufacturers of the coatings.
2. The total color differences, ΔE^*_{ab}, were computed from the Illuminant C readings. These readings were taken before immersion or exposure and at the end of the basic 3,000 hour immersion and exposure periods.
3. The chalk ratings are based on the visual scales in Pictorial Standards of Coatings Defects. A rating of 2 on the 2, 4, 6, 8, and 10 scale refers to very heavy chalking, while a rating of 10 refers to an absence of chalking.
4. The numbers of hours recorded are the numbers of hours of exposure as of the time the panels were examined. The exact numbers of hours before initial blistering took place are unknown. However, in no instance would the numbers of hours be less than the recorded numbers of hours by more than 1 weeks' exposure time, approximately 164 to 168 hours.

Table 11b - Summary of test data - average values for each coatings systems

System No.	Total target DFT (mils)[1]	One-inch Mandrel bend test				Brookfield viscosity (topcoat) cPx10^3 (Pa · s)[4]		Blasting media impact abrasion test[5]		General coating properties (topcoat systems)					
		Cracking		Some loss of cohesion						Min. No. of coats for 60 mils DFT[1]	Min. curing time before immersion C 75 °F (days)[1]	Primer/tie coat required[1]		Recoating time C 75 °F (topcoat) min.-max. (hours)[1]	Pot life C 70-75 °F (topcoat) (hours)[1]
		Yes	No	Yes	No	(15-min.)	(End)	(mg loss)	(mg/min loss)			Yes	No		
25	70.5		X		X	3.20x10^3	8.00x10^3	415.3	13.8	3	4	X		0.33 to 1	1.50
26	71.0		X		X	98.40	118.00	838.8	28.0	2	4	X		0.33 to 4	1.50
27	70.5		X		X	23.60	20.20	[2]1,027.0	178.6	3	4	X		2 to 72	1.00
28	69.0		X		X	496.00	976.00	[2]1,013.5	75.1	6	7		X	6 to 48	2.50 (60 °F)
29	69.0		X		X	117.00	131.00	1,189.0	39.6	3	7		X	6 to 168	1.25
30	70.0 to 71.0		X		X	10.40	66.40	559.0	18.6	4+	1/3	X		1 to 72	N/A
31	71.0		X		X	0.88	12.20	401.5	13.4	5	7	X		0.5 to 6	0.75
32	71.0		X		X	20.40	200.00	223.0	7.4	2	7	X		16 to 96	0.75
33	69.0		X		X	226.00	860.00	656.5	21.9	[6]1	1		X	firm to 4	0.50
34	69.0		X		X	12.20	8.08	[3]578.4	62.5	3	5		X	<2 to 48	2.00
Epoxy control[3]	17.2		--		--	--	--	[3]440.1	1,553.5	--	--	--	--	--	-

Notes

1. See note No. 1 of table 11a.
2. The elastomeric topcoat was removed from the epoxy basecoat before completion of the full 30-minute testing period.
3. The epoxy control was an epoxy coating which has been widely, and so far successfully, used by Reclamation. Actual average dry-film thickness (DFT) was 17.2 mils. The epoxy coating was removed from the substrate before the completion of the full 30-minute testing period.
4. The Brookfield viscosity studies (topcoats only) were conducted at 76 to 78 °F (24.4 to 25.6 °C).
5. Bureau of Reclamation (BOR) designed test method.
6. Squeegee on a flat surface. Three coats may be required for spray application on a vertical surface.

Table 12. - Manufacturers' testing methods[1,5]

System No.	Elongation	Tensile strength	Tear strength	Hardness Shore A	Adhesion
25	ASTM D 412 DIE 'B' 80 mils DFT film 77 °F (25 °C) 20 inches/min[4]	ASTM D 412 DIE 'B' 80 mils DFT film 77 °F (25 °C) 20 inches/min[4]	ASTM D 470 80 mils DFT film 77 °F (25 °C) 20 inches/min[4]	ASTM D 2240 80 mils DFT film 77 °F (25 °C)	ASTM D 429 Method B 65 pli N/A[3]
26	ASTM D 412 DIE 'B' 80 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 412 DIE 'B' 80 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 470 80 mils DFT film 77 °F (25 °C) 20 inches/min ASTM D 624 DIE 'C' 80 mils DFT film 77 °F (25 °C) 20 inches/min[4]	ASTM D 2240 80 mils DFT film 77 °F (25 °C)	ASTM D 429 Method B 75 pli N/A
27	ASTM D 412 DIE 'C' 30 mils DFT film 70 to 75 °F (21.1 to 23.9 °C) 40 to 50 percent R.H.	ASTM D 412 DIE 'C' 30 mils DFT film 70 to 75 °F (21.1 to 23.9 °C) 40 to 50 percent R.H.	ASTM D 1004 30 mils DFT film 70 to 75 °F (21.1-23.9 °C) 40 to 50 percent R.H. 2 inches/min	ASTM D 2240 1/4-inch DFT, total 70 to 75 °F (21.1-23.9 °C) 40 to 50 percent R.H.	Own method, qualitative N/A
28	ASTM D 2370 10 mils DFT free film 77± 2 °F (25±1.1 °C) 50 percent R.H. 1- x 1/2-inch area tested	ASTM D 2370 10 mils DFT free film 77±2 °F (25±1.1 °C) 50 percent R.H. 1- x 1/2-inch area tested	N/Av[2]	ASTM D 2240 77±2 °F (25±1.1 °C) 50 percent R.H.	ASTM D 4541 4 mils epoxy DFT 9 to 11 mils elastomer DFT Hot rolled steel (3-mm-thick panel) 77±2 °F (25±1.1 °C) 850 psi (5,860 kPa)
29	ASTM D 412 DIE 'C' 30 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 412 DIE 'C' 30 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 624 DIE 'C' 30 mils DFT film 77 °F (25 °C) 20 inches/min ASTM D 1938 30 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 2240 1/4-inch DFT 77 °F (25 °C)	ASTM D 4541 2 to 4 mils epoxy primer DFT 20 mils elastomer DFT (1/4-inch steel panel) 77 °F (25 °C) 1,300 to 1,700 psi (8,962-11,720 kPa)
30	ASTM D 412 DIE 'C' 30 to 40 mils DFT film 78 °F (25.6 °C) 20 inches/min	ASTM D 412 DIE 'C' 30 to 40 mils DFT film 78 °F (25.6 °C) 20 inches/min	ASTM D 1004 30 mils DFT film 78 °F (25.6 °C) 2 inches/min	N/Av	ASTM D 4541 5 mils epoxy primer DFT 1 mil primer/tie coat DFT 50 to 65 mils elastomer DFT (1/4-inch steel panel) 65 °F (18.3 °C) 710 psi (4,895 kPa) Same as above but without primer/tie coat 380 psi (2,620 kPa)

Table 12. - Manufacturers' testing methods - Continued

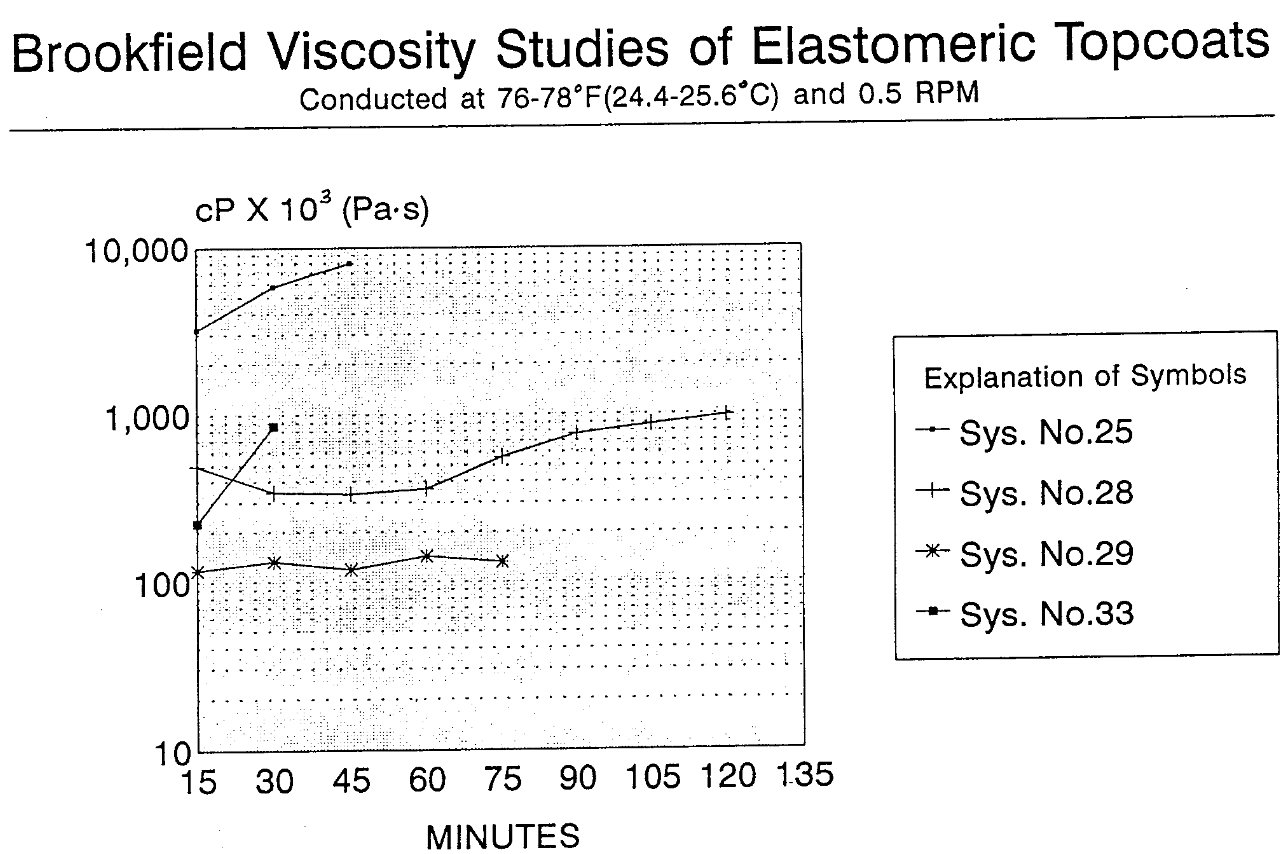
System No.	Elongation	Tensile strength	Tear strength	Hardness Shore A	Adhesion
31	ASTM D 412 DIE 'C' 57 to 62 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 412 DIE 'C' 57 to 62 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 624 DIE 'C' 57 to 62 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 2240 72 °F (22.2 °C)	ASTM D 429 70 pli N/A
32	ASTM D 412 DIE 'C' 85 to 90 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 412 DIE 'C' 85 to 90 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 624 DIE 'C' 85 to 90 mils DFT film 77 °F (25 °C) 20 inches/min	ASTM D 2240 72 °F (22.2 °C)	N/Av
33	ASTM D 412 DIE 'C' 100 mils DFT film 78 °F (25.6 °C)	ASTM D 412 DIE 'C' 100 mils DFT film 78 °F (25.6 °C)	ASTM D 624 DIE 'C' 100 mils DFT film 78 °F (25.6 °C) 20 inches/min	ASTM D 2240 100 mils DFT 78 °F (25.6 °C)	ASTM D 4541 60 mils DFT Over dry concrete 350 psi (2,413 kPa) N/A
34	ASTM D 412 DIE 'C' 20 mils DFT film 78 °F (25.6 °C)	ASTM D 412 DIE 'C' 20 mils DFT film 78 °F (25.6 °C)	ASTM D 470 20 to 40 mils DFT film 78 °F (25.6 °C) 20 inches/min ASTM D 624 DIE 'C' 20 to 40 mils DFT film 78 °F (25.6 °C) 20 inches/min	ASTM D 2240 10 to 40 mils DFT 78 °F (25.6 °C)	ASTM D 429 >CS Adhesion strength greater than coating film adhesive strength N/A

Notes

1. The information which appears in this table was provided by the coatings manufacturers who participated in the investigation. Additional information, if required, may be obtained from these manufacturers.
2. N/Av = Not available. Manufacturer did not run this test.
3. N/A = Not applicable. The substrate for the polyurethane elastomer was steel or concrete instead of epoxy.
4. The standard rate of pull is 20 inches/min.
5. F or specific values of the elongation, tensile strength, tear strength, and hardness tests, please refer to table 2.

Table 13. Results of post-immersion pulloff adhesion tests.

System No.	Condition No.	Pulloff adhesion - 3 pulls				Middle Pull, Post-Immersion Remarks
		Post-Immersion lb/in²	(kPa)	Main Report lb/in²	(kPa)	
26	1	283	1951	567	3909	90% to bond coat; 6% to basecoat topcoat; 4% to basecoat primer
26	2	493	3399	567	3909	80% to basecoat topcoat; 20% intracoat, basecoat topcoat
26	3	410	2827	567	3909	40% to basecoat topcoat; 60% to substrate
29	1	572+	3943+	512	3530	80% to basecoat topcoat; 20% intracoat, basecoat topcoat
29	1	----	----	----	----	Could not be tested because of topcoat condition
29	3	----	----	----	----	Not tested
30	1	275	1896	320	2206	100% to basecoat topcoat
30	2	----	----	----	----	Could not be tested because of topcoat condition
30	3	----	----	----	----	Not tested
31	1	258	1779	240	1655	Only the middle pull gave a result. 8% to basecoat topcoat; 80% intracoat, basecoat topcoat; 12% to basecoat primer
31	2	375	2585	240	1655	Primarily glue line failure. Only the top pull gave a result. It was 20% to bond coat; 80% intracoat, basecoat topcoat
31	3	318	2192	240	1655	20% intracoat, basecoat topcoat; 65% to basecoat topcoat; 10% to basecoat primer

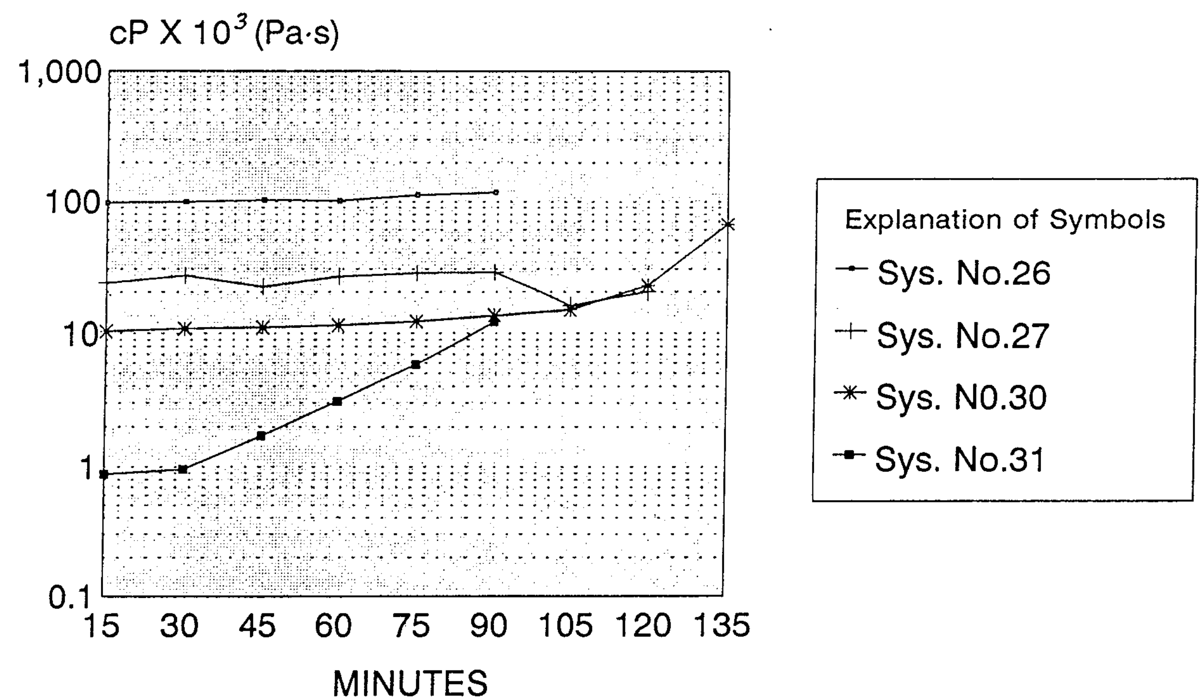


Stated pot lives of Systems No. 25, 28, 29, and 33 were 1.50, 2.50, 1.25, and 0.50 hours. respectively.
System No. 25 was beyond the range of the viscometer after 45 minutes.
The stated pot life of System No. 28 was at 60 °F (15.56 °C).

Figure 1. Brookfield viscosity studies of Systems No. 25, 28, 29, and 33.

Brookfield Viscosity Studies of Elastomeric Topcoats

Conducted at 76-78°F(24.4-25.6°C) and 0.5 RPM



Stated pot lives of Systems No. 26, 27, and 31 were 1.50, 1.00, and 0.75 hours, respectively.
System No. 30 was a one-package system that did not have a stated pot life.

Figure 2. Brookfield viscosity studies of Systems No. 26, 27, 30, and 31.

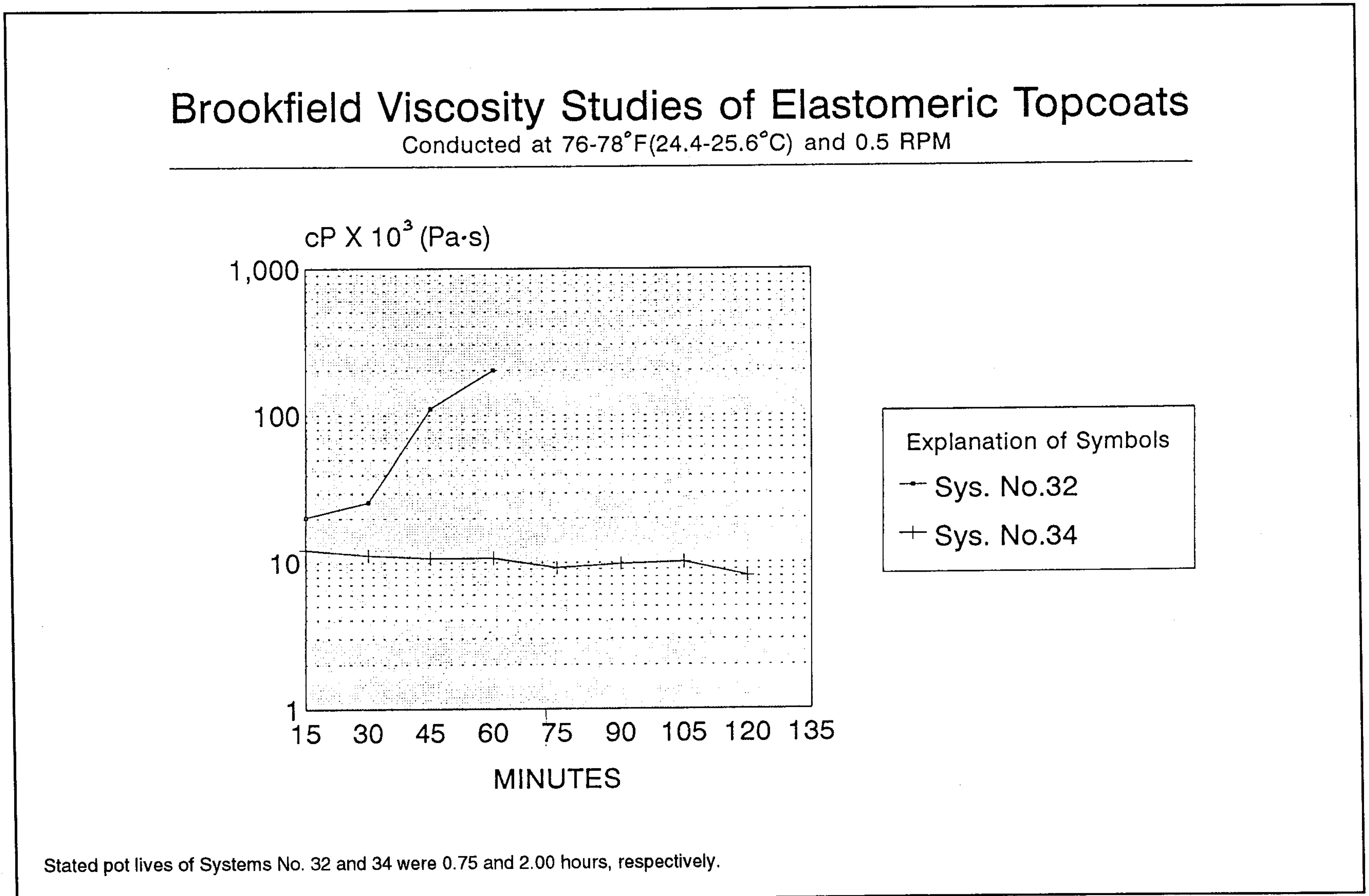
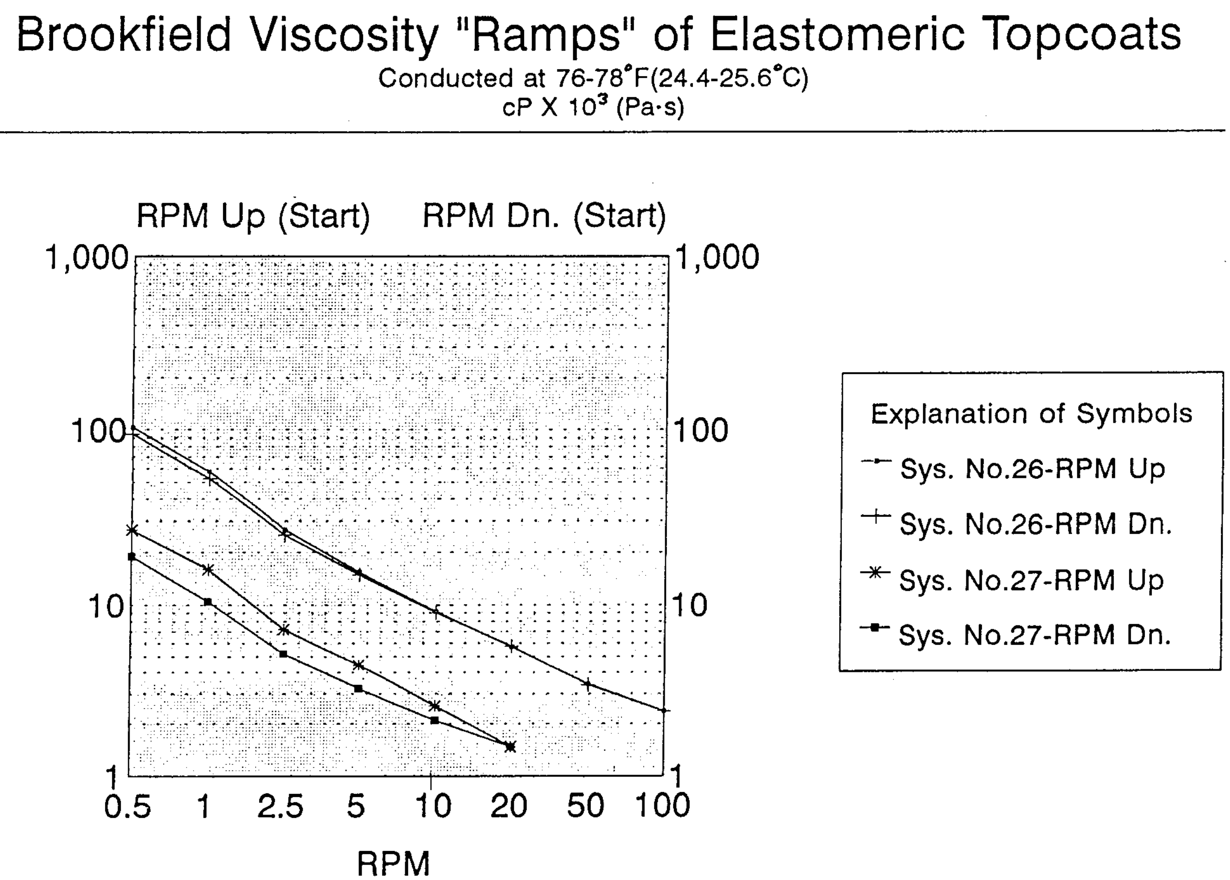


Figure 3. Brookfield viscosity studies of Systems No. 32 and 34.



System No. 25 had no "ramp." A ramp was beyond the range of the viscometer.

Figure 4. Brookfield viscosity ramps of Systems No. 26 and 27.

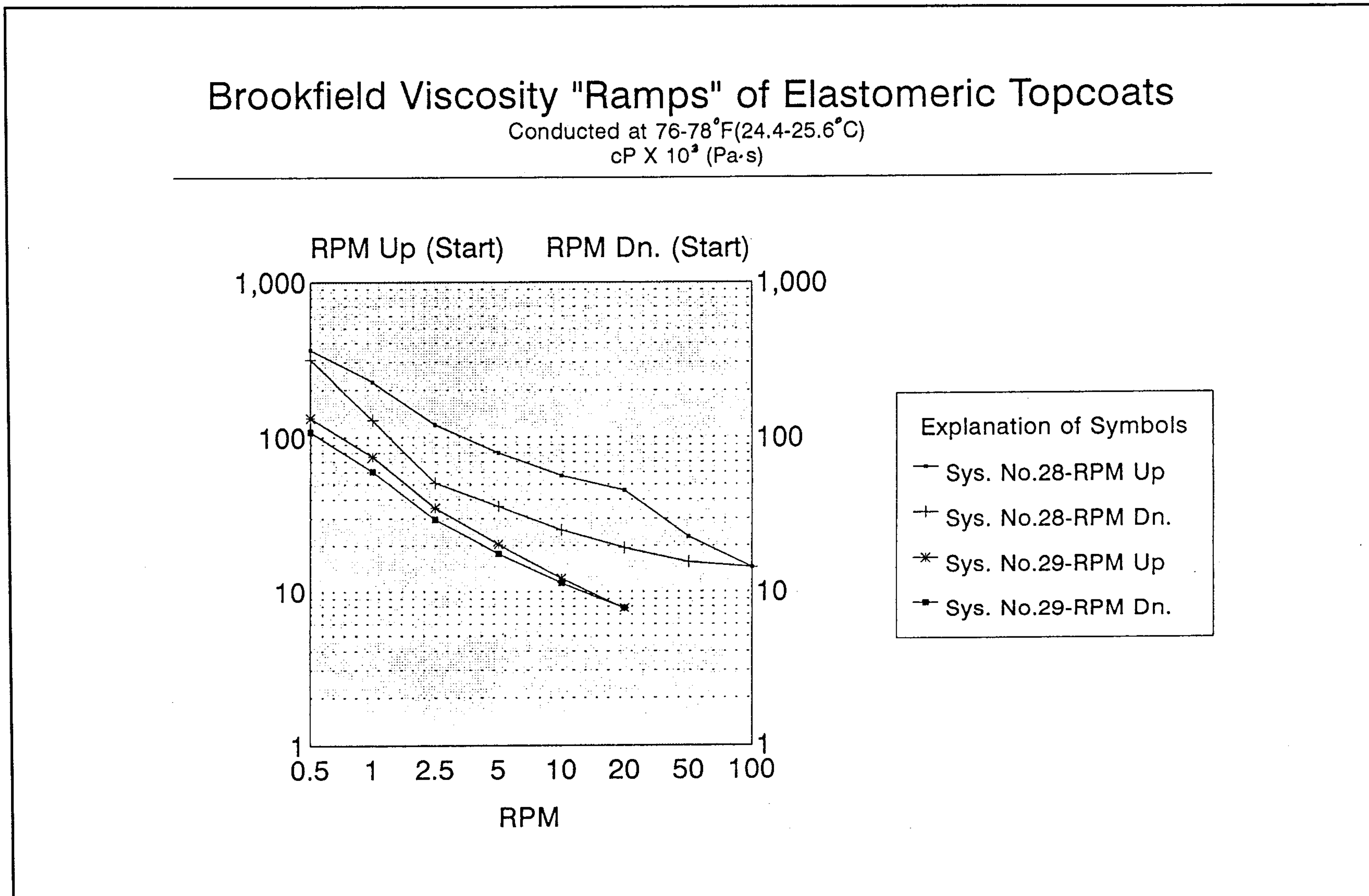


Figure 5. Brookfield viscosity ramps of Systems No. 28 and 29.

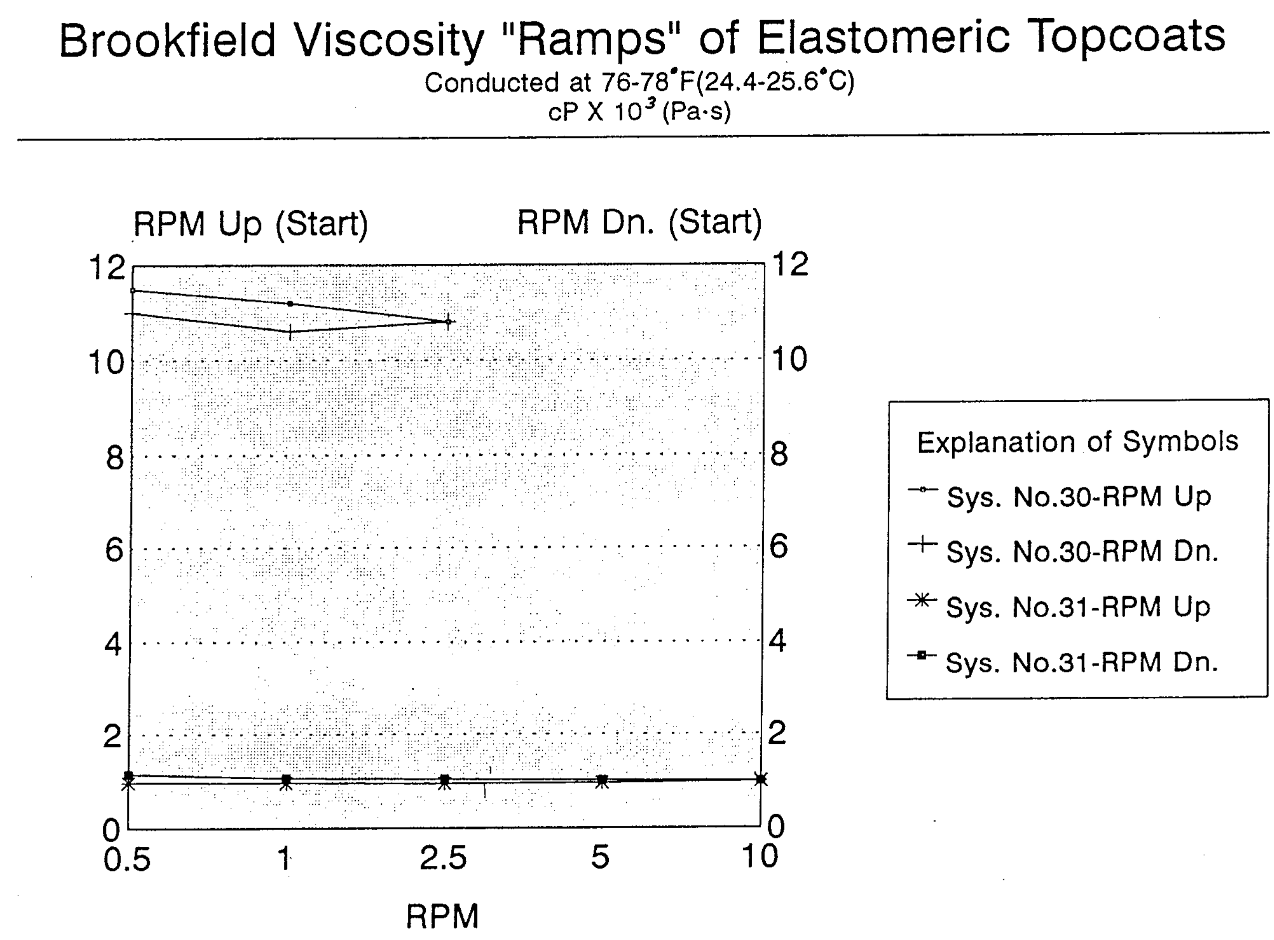


Figure 6. Brookfield viscosity ramps of Systems No. 30 and 31.

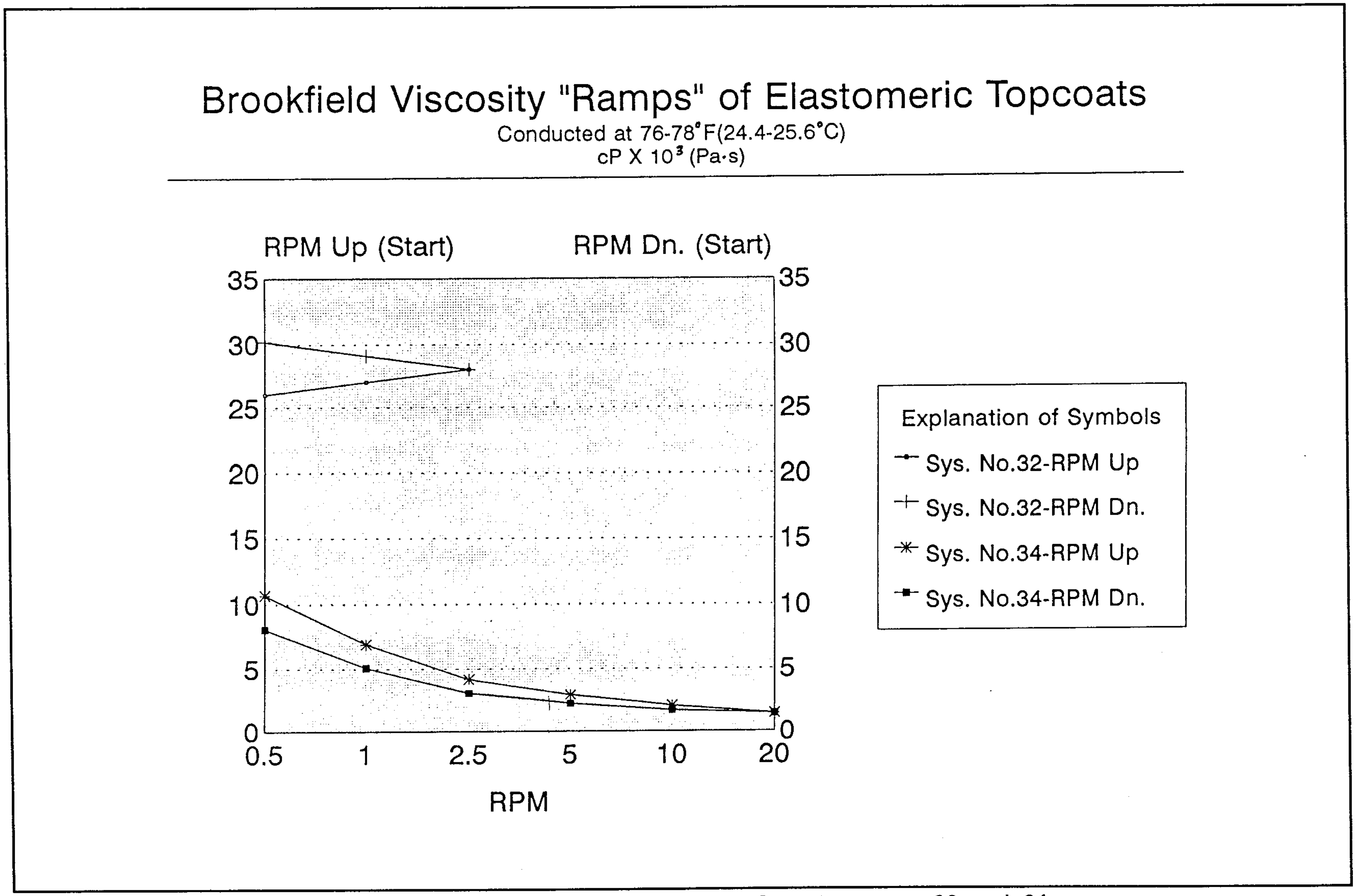


Figure 7. Brookfield viscosity ramps of Systems No. 32 and 34.

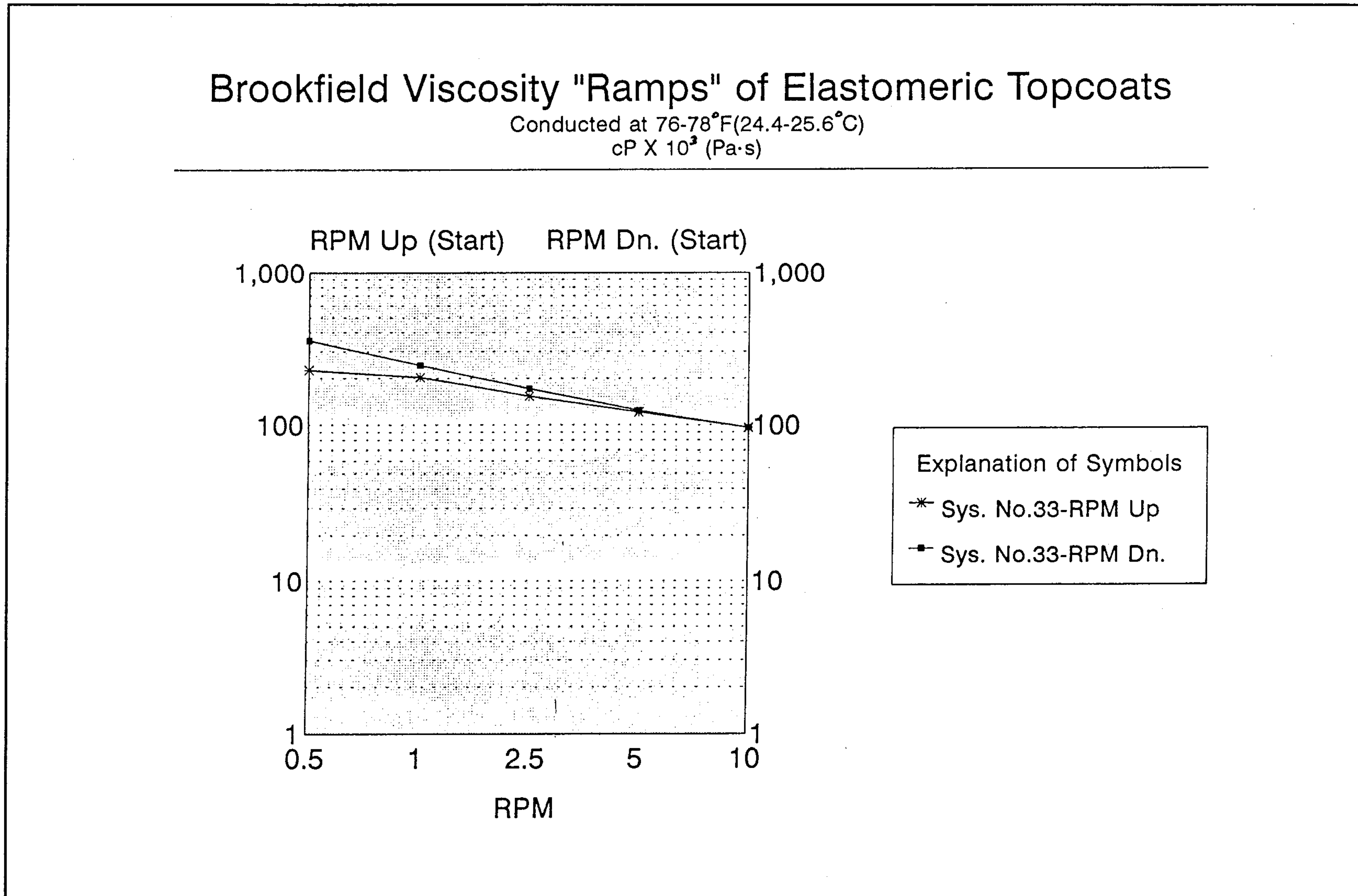


Figure 8. Brookfield viscosity ramps of System No. 33.

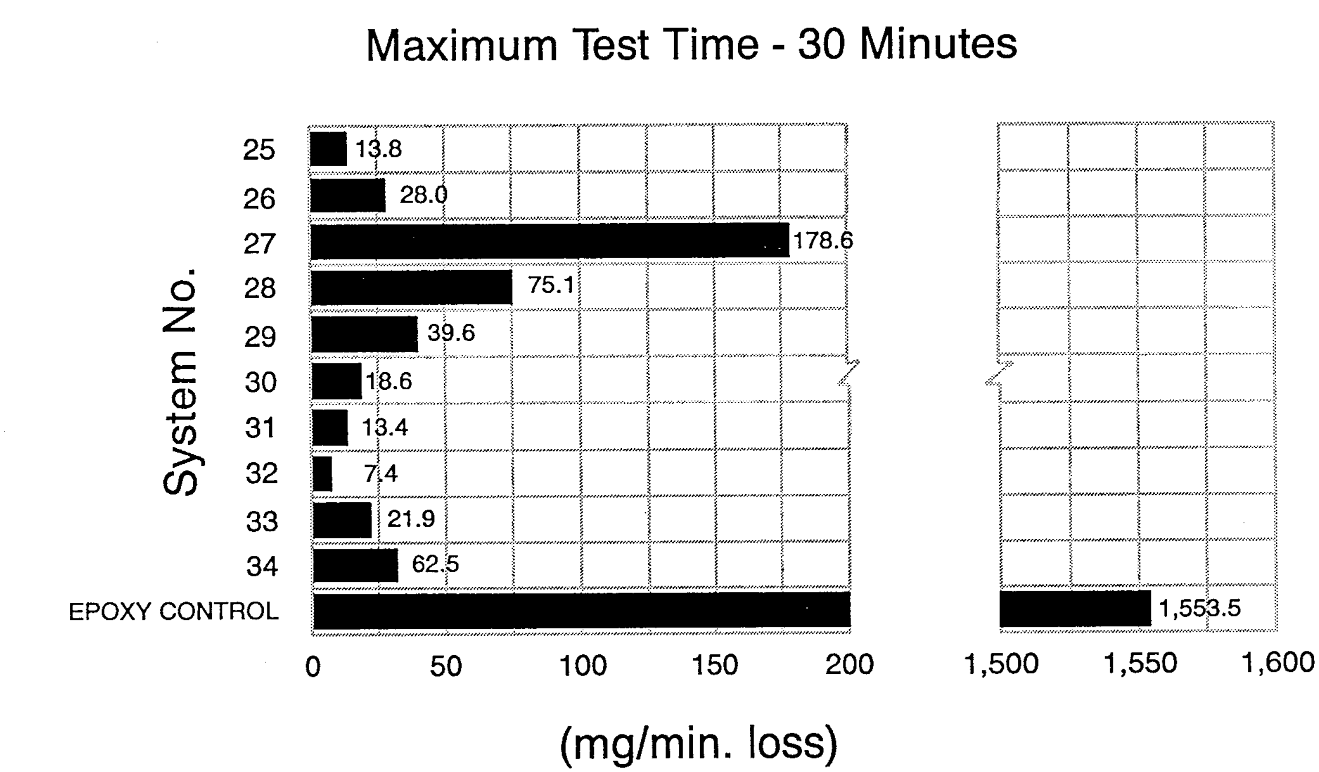


Figure 9. Blasting media impact abrasion test.

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The Corps of Engineers has used solution vinyl paints for the corrosion protection of hydraulic structures on inland waterways for many years. These coatings have an excellent service life; however, the liquid paint contains high quantities of solvents. To comply both with existing and anticipated pollution regulations, it is necessary to evaluate potential coatings to replace those currently used.

Ten elastomeric polyurethanes were tested in the laboratory; six were recommended for field testing. They were applied to an epoxy basecoat system consisting of MIL-P-24441/29 F150, Type IV primer and MIL-P-24441/30 F151, Type IV topcoat. This epoxy system is the latest and lowest-VOC version of MIL-P-24441. The report includes laboratory and field test results.

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